EFFECT OF PHOSPHORUS AND SULPHUR ON THE GROWTH AND YIELD OF MUSTARD

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EFFECT OF PHOSPHORUS AND SULPHUR ON THE GROWTH AND YIELD OF MUSTARD

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This is to certify that thesis entitled, **"EFFECT OF PHOSPHORUS AND SULPHUR ON GROWTH AND YIELD OF MUSTARD"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **SOIL SCIENCE,** embodies the result of a piece of bonafide research work carried out by **MD. MONIRUZZAMAN, Registration No.18-09041** 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.

Dated:
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DEDICATED TO

MY

BELOVED PARENTS

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Abstract

A field experiment was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka 1207 during November 2018 to February 2019 to study the effect of phosphorus and sulphur on the growth and yield of mustard (Bari sarisa-14). The experimental soil was clay loam in texture having pH of 5.7. The experiment included three levels of phosphorus viz. 0, 28, and 36 kg P ha^{-1}and three levels of sulphur viz., 0, 16, and 20 kg S ha^{-1}. The experiment was laid out in a Randomized Complete Block Design with three replications. Phosphorus showed significant effect on yield and yield attributes of mustard. Application of phosphorus (P_3 @36 kg ha^{-1}) produced the highest seed yield, plant height, number of primary branches plant^{-1}, number of siliqua plant^{-1}, and 1000-seed weight. Sulphur fertilizer also had significant effect on yield and yield attributes of mustard. Application of sulphur @ 20 kg ha^{-1} produced the highest number of primary branches plant^{-1}, number of siliqua plant^{-1}, but in all the cases relatively, the lower response was found from the control treatment. Phosphorus in combination with sulphur showed significant effect on yield and yield attributes of mustard. Plant height, no. of siliqua plant^{-1}, siliqua length, no. of seed siliqua^{-1}, weight of 1000 seed (g), seed yield was found the highest in the treatment combination P_3S_3. The addition of P and S not only increased the yield but also protect the soil from total exhaustion of nutrients.

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LIST OF ABBREVIATION AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
BBS	=	Bangladesh Bureau of Statistics
FAO	=	Food and Agricultural Organization
P	=	Phosphorus
S	=	Sulphur
et al.	=	And others
TSP	=	Triple Super Phosphate
MOP	=	Muirate of Potash
RCBD	=	Randomized Complete Block Design
DAT	=	Days after Transplanting
ha^{-1}	=	Per hectare
g	=	gram (s)
kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources Development Institute
wt	=	Weight
LSD	=	Least Significant Difference
^{0}C	=	Degree Celsius
NS	=	Not significant
Max	=	Maximum
Min	=	Minimum
%	=	Percent
NPK	=	Nitrogen, Phosphorus and Potassium
CV%	=	Percentage of Coefficient of Variance

Chapter I

Introduction

Mustard (*Brassica compestris* L.) belongs to the family Brassicaceae commonly known as Shorisha and is an important rabi season oilseed crop of Bangladesh. Mustard is second largest edible oilseed crop after groundnut, accounts nearly 30% of the total oilseeds produced in Bangladesh. Mustard has been reported to be a common crop in crop rotation, increasing crop intensity as it boosts wheat and barley yields and breaks disease cycles in cereal grains. The area and production of mustard of our country was about 0.481 million hectares and 0.536 million tons, respectively with an average yield of 1.11 t/ha during 2010-2011 (AIS, 2012). It has an extraordinary demand for edible oil in Bangladesh. Mustard tops the list among the oil seed crops grown in this country in respect of both production and acreage (BBS, 2004). In terms of domestic demand, Bangladesh suffers from acute shortages of edible oil. About 2/3 of the total edible oil consumed in the country is imported. While domestic production has significantly increased, due to increased requirements for edible oil, the deficiency has not decreased.

Generally two main methods of sowing are followed in Bangladesh for mustard cultivation. They are line sowing and broadcasting. In line sowing, seeds are sown in separate line by maintaining plant to plant distance. Line sowing can ensure optimum plant population per unit area thereby increasing the yield of mustard. In broadcasting, seeds are sown haphazardly. As a result, it is difficult to maintain desired plant population per unit area which is important to obtain higher yield. A suitable technique of sowing of mustard is to be found out for higher yield.

Edible oil is an essential integral part of the daily diet of the people in Bangladesh. Fats and oils from various sources, such as animals and plants, are available. Animal fats are extracted from milk, ghee, butter, etc., but they are very expensive compared to the oil obtained from various oil crops. Plant oil is easily digestible and has a better nutritional quality than animal fats. Plant products supply more energy than animal products. Oil extracted from coconut, groundnut or mustard, for example, provides 900 kilocalories (energy) against butter and fist that provide 729 and 273 kilocalories, respectively. It is evident that vegetable oil which may be obtained from plant sources by cultivation of oil crops is no less important than animal fat for energy.

Every year Bangladesh imports 2085864 metric tons of edible oil to meet up the annul requirement of the country, which costs Tk.64430 million (BBS, 2007). Since 1990, both crop acreage and production have decreased primarily due to the introduction of cereal crops such as rice, maize, wheat, etc. Chemical fertilizers have greatly contributed to water, air and soil contamination. Therefore, the latest trend is to explore the possibility of supplementing eco-friendly and cost-effective chemical fertilizers with organic ones.

Now-a-days Bangladesh is facing a huge deficit of edible oil (BBS. 2002) According to the National Nutrition Council (NNC) of Bangladesh. The recommended dietary allowance (RDA) is estimated to be 6 g oil per day for a diet with 2700 Kael (NNC, 1984). On this RDA basis. Bangladesh requires 0.29 million tons of oil equivalent to 0.8 million tons of oilseeds for nourishing her people (FM), 1998).

Phosphorus (P) promotes root development and enlargement (Russel and Appleyapd, 1915), 149 affect seed germination, cell wall division, flowering, fruiting, synthesis of fat, starch and in fact most biochemical activities (Singh and Singh, 2012).Phosphorus fertilization is of prime importance for normal growth and development of plants because of its vital role in chlorophyll synthesis and involvements in various physiological and metabolic processes of the plant (Mehta *et al*., 2005). Phosphorus has an important role in the process of photosynthesis of plants (Arnon, 1953).

Sulphur is the fourth vital plant nutrient after nitrogen, phosphorus and potassium for agriculture. It is essential for synthesis of amino acids, proteins, oils, component of vitamin A and activates enzyme system in plant. Three amino acids viz. methionine (21% S), cysteine (26% S) and cystine (27%S) contain S which are the building blocks of proteins. About 90% of sulphur is present in these amino acids. Sulphur is also involved in the formation of chlorophyll, glucosides and glucosinolates (mustard oils), activation of enzymes and sulphydryl (SH-) linkages that are the source of pungency in oilseeds. Adequate sulphur is therefore very much crucial for oilseed crops. Sulphur is also a constituent of vitamins biotine and thiamine (B1) and also of iron sulphur proteins called ferrodoxins. Sulphur is associated with the production of oilseed crops of superior nutritional and market quality. Sulphur is involved in the synthesis of essential amino acids like eystcine, cystine and methionine (Kumar and Yadav, 2007). Sulphur plays an important role in mustard plant metabolism as a component of proteins and formation of flavouring compounds known as glucosinolates. It is taken up by the roots as sulphate and transported via the xylem to the leaves where it is reduced to cysteine and either converted to methionine or incorporated into proteins and cysteine containing peptides such as glutathione (Orlovius and Kirkby, 2013). The S containing amino acids (e.g., cystine, cysteine and methionine) are precursors of other secondary plant products like S-containing plant products of Brassica species such as glucosinolates and coenzymes. Glucosinolates are preformed resistance barriers contributing general plant defence mechanism (Schlösser, 1983). Sulphur is essential for protein formation, important for high protein content, a component of vitamin A and activates certain enzyme systems in plants (Havlin *et al*., 2004).

Moreover, Phosphorous and sulphur are closely related to each other because both of these elements are necessary for the synthesis of proteins and their quantity is always maintained at a constant ratio in plant tissue (Dijshorn *et al*, 1960).In addition, the fertilizer requirement for maximum growth and yield of newly developed mustard variety is not much investigated. With a view to determine the nitrogen and sulphur requirement of this new variety a field study was conducted with the fallowing objectives:

1. To determine the different level of phosphorus on the growth and yield of mustard.

2. To determine the different level of sulphur on the growth and yield of mustard.

3. To study the interaction effect of sulphur and phosphorus on the growth and yield of mustard.

Chapter II

Review of Literature

It is now understood that agriculture applies not only to the production of crops, but also to numerous other variables responsible for crop production. Some of the published reports relevant to research topic are reviewed under the following headings:

2.1 Effect of phosphorus on growth and yield of mustard

Mir *et al.* (2007) was conducted an experiment on mustard (*Brassica juncea L.*) (Czem & Coss var. Alankar) at Aligarh to study the effect of different combinations of phosphorous and potassium applied as monocalcium superphosphate and muriate of potash respectively (each at the rate of 30, 60, 90 kg P_20_5 and K_20 ha^{-1} on yield and yield attributes of mustard. In addition, a uniform dose of urea at the rate of 80 kg N $ha^{-1}$was applied. At harvest, various yield characteristics including number of pods per plant, number of seed /pod. Seed yield and oil yield were studied. The effect of phosphorus alone as well as in combination with potassium was significant. Treatments 60 kg P_20_5 ha^{-1} and 60 kg P_20_5 - 60 kg K_20 ha^{-1} proved optimum and the increase in seed yield was due to increase in pods/ plant and seeds /pod.

Bhat *et. al*. (2006) conducted a pot experiment to study the effect of three levels of nitrogen and phosphorus combinations, i.e. No P30 kg ha^{-1}, NSO P40 kg ha^{-1} and N3 (P50 kg ha^{-1} 'on growth. yield and quality of two cultivars of mustard (*Brassica jancea*). The data revealed that cultivar Pusa Bold gave higher plant height, leaf number, leaf area, number of primary branches and plant dry weight than Kranti. Application of higher dose of NP fertilizers. i.e (. P50 kg ha^{-1} proved significantly better in improving all these parameters. Higher fertilizer dose also resulted in a significant increase in number of siliqua per plant, length of siliqua and number of seeds/siliqua which consequently resulted in a marked increase in harvest index and seed yield of both the cultivars. N® P50 kg ha^{-1} also resulted in an overall increase in leaf N, P and K contents and seed protein content. Oil content was found to be decreased with increased dose of NP fertilizers, however, extent of decrease in seed oil content was lower than increase in seed yield and thus total edible oil production was still higher with higher fertilizer dose as compared to the normal recommended dose

Premi (2004) conducted a field experiment during winter to study the effect of nitrogen and phosphorus levels on growth, yield attributes, yield and oil content of Indian mustard *Brassica juncea*. Significant increase in number of siliquae per plant up to 120 kg N/ha and number of seeds per siliqua up to 80 kg N ha^{-1} resulted in significant increase in seed yield up to 120 kg N/ha. N levels did not affect Siliqua length and 1000-seed weight. With addition of nitrogen above 80 kg N ha^{-1} reduced the oil content. Response to phosphorus was observed up to 80 Kg P_20_5 ha^{-1} with respect to seed yield and oil content

Birbal *et al.* (2004) carried out an experiment in India during 1996/97 and 1997/99 rabi seasons with 4 levels of phosphorus viz. 0. 25, 50 and 75 kg P/ha. They observed increased number of branches with increasing level of phosphorous and found maximum number of branches per plant at 75 kg P/ha.

Kantwa and Meena (2002) conducted an experiment in indian for mustard (*Bassica juncca*) with different levels of phosphorus viz. 15, 30 and 45 kg/ha. They reported that application of phosphorus up to 45 kg/ha significantly increased the number of siliqua per plant.

Cheema *et.al*. (2001) reported the result of a field study to investigate the influence of various rates of N and P fertilizers in splits at various times on the growth and the seed and oil yields of canola (*Brassica napus I.*) during 1995-97. The results showed that seed and oil yields of canola were maximized at the

90/60 kg N/P_20 ha^{-1} rate of application under the agro-ecological conditions of Faisalabad, Pakistan

Chaubey *et al.* (2001) perlirmed an experiment during the rahi season to evaluate the response of mustard (*Brassica juncca)* with 3 levels of phosphorus. They observed that plant height increased significantly with the increase of P_20_5 up to 60 kg/ha.

Davaria *et. al*. (2001) carried out an experiment during rahi season to determine the effect of phosphorus on the yield and yield attributes of mustard cv. Gujrat Mustard with 3 levels of phosphorus viz. 0. 25 and 50 kg/ha. The maximum thousand seeds weight was found with 50 kg P/ha.

Kakai *el. al*. (1999) conducted an experiment to determine the effect of different NP combinations on the growth, seed yield and oil content of three mustard genotypes at the Latif experimental farm, Sind Agriculture University. Tandojarri on non-saline and non-sodic medium textured soil. The NP levels comprised 0-0, 50-I5. 75-30, 100-45. 125-60 and 150-75 kg NP/ ha while the genotypes were early Raya. P-53/48-2 and 8-9. The results revealed that NP fertilizer increased significantly all the agronomic traits of this three genotypes. However, the difference between 150-75 and 125-60 kg NP levels was non-significant for all the traits including seed oil content. Among the genotypes, 5-9 gave significantly higher seed yield but seed oil content was the highest in early Raya.

Anwar *et al.* (1992) concluded that 100-70 kg NP ha was the optimum dose both for yield and protein contents and gave higher benefit-cost ratio (1:4).

Ali and Rehman (1986) reported that increasing rate of N up to 160 kg ha^{-1} with Phosphorus consistently increased the growth and yield components.

Anand (1992) observed the effect of three sub-surface drain spacing and three levels of phosphorus on the yield, chemical composition and uptake of nutrients by Indian mustard (*Brassica juncea*). The number of siliqua nY2 and seed yield decreased with increasing drain spacing. Application of phosphorus increased seed yield and yield attributes. The concentrations of nitrogen, phosphorus and potassium in the seed and stalks decreased and those of sodium, calcium and magnesium increased with increasing drain spacing, but application of phosphorus increased the concentration of these nutrients in the seed and stalks. Absence of phosphorus in the drain water effluent and the level of available phosphorus in the soil profile after crop harvest indicated very slow movement of phosphorus, most of which was retained in the top 30cm of soil

Pinkerton (1991) found the effect on oilseed rape and Indian mustard grown in a glasshouse to derive values for a tissue test for the diagnosis of phosphorus (P) deficiency. Seven rates of P. combined factorial with 3 rates of nitrogen (N), were used to determine critical P concentrations. The critical values reported where critical P levels in whole rape shoots adequately supplied with N decreased from 0.29% at the early rosette stage to 0.21% at the late rosette or yellow bud stage, while critical values in mustard fell from 0.25% at the early rosette stage to 0.18% at stem elongation to MI flower. Critical P concentrations for prediction of seed yield were slightly higher (0.05% higher at the rosette stage).A nutrient supply with high P and high N reduced the seed oil concentration of both species; a low P and high N supply reduced the oil concentration in rape seed but increased it in mustard seed

In field trials at Mymensingh K. 10, 12 or 14 kg *Brassica juncea* / ha was (a) broadcast and given 5 t cattle manure/ha + I hand weeding and given 90 kg N. 80 kg P and 30 kg K/ha i I weeding + I irrigation or (d) broadcast and given ISO kg N, 140 kg P. 60 kg Mm. 2 weeding, 2 irrigations and sprayed with insecticide. Yield and yield components were not significantly affected by sowing rate but were highest at 8 kg seeds/ha. Seed yield, plant height. Number of primary and secondary branches and filled siliqua/plant. Fertile seeds/siliqua and DM yield were highest with management system (d) (Gaffer and Mohammad. 1988)

Mudhalker and Ablawat (1981) stated that growth and yield components were increased with increasing rates of N (0-80 kg ha^{-1}) and P (0-80 kg ha^{-1}), Reauz *et al* (1983) reported that fertilizer containing nitrogen and phosphorus resulted in higher yield of rapeseed than wheat

Chatterjee *et al* (1985) conducted a field experiments in 1980-3 on intensively cultivated sandy loam soils containing 75-100 p.p.m. S, 0.05-0.06% Ca. 5 p.p.m. B. 12-I5 p.p.m. Zn. 16 kg and 96 kg available P and K/ha rapeseed revealed that application of 20 kg S/ha through gypsum in conjunction with borax (10 kg/ha) produced a 42% increase in the seed yield of Brassica juncea. Borax zinc sulphate equivalent to 20 kg S/ha and gypsum when applied alone produced a 34. 26 and 39% increase in yield of Resp. Combination of these nutrient products, however, did not show any additive effect. The increase in yield was mainly due to an increase in the number of siliqua/plant and 1000-seed weight.

Bhan and Amar Singh (1976) found that the average seed yield was the maximum when 120 kg nitrogen, 30-60 kg phosphorus and 40 kg potassium per hectare were applied

Dembinaki *et.al*. (1969) found that phosphorus dose up to 180 kg ha' increased yield and oil content in winter rape.
Bhan and Amar Singh (1976) stated that the average seed yield was the highest when 4080kg nitrogen, 30-60 kg phosphorus and 40 kg potassium per hectare were applied.

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2.2 Effect of Sulphur on growth and yield of mustard

Katiyar *et al.* (2014) reported that application of sulphur 90 % DP @ 25 kg ha^{-1} basal had significant influence on yield attributes and grain yield of mustard. Maximum value of seeds per pod, thousand grain weight and grain yield were recorded with dual application basal along with 80% WP @ 1.25 kg ha^{-1} foliar sprayed at 75 DAS closely followed by application of sulphur as basal + 80% WP @ 5 kg ha^{-1} applied with urea broadcasting at 45 DAS and minimum value under farmers practice

Katiyar *et al.* (2014) reported that growth parameters were influenced significantly due to application of different sulphur containing fertilizers. Maximum plant height was recorded with dual application of sulphur as basal along with 80% WP @ 1.25 kg / ha foliar sprayed at 75 DAS closely followed by application of sulphur as basal + 80% WP @ 5 kg ha^{-1} applied with urea broadcasting at 45 DAS and minimum value under farmers practice

Rao *et al.* (2013) reported that sulphur application significantly influenced the yield attributing characters and yield over control. Application of sulphur @ 45 kg ha^{-1} through gypsum recorded highest number of filled pods per plant, 100 pod weight, 100 kernel weight, pod yield, haulm yield of the kernels. Application of gypsum at 45 kg ha^{-1} has increased the pod yield to the tune of 52.2%.

Sah *et al.* (2013) reported that application of sulphur resulted into significant variation in growth characters of Indian mustard

Rao *et al.* (2013) reported that sulphur application significantly influenced the growth of mustard over control regardless of sources of sulphur. Application of sulphur @ 45 kg ha^{-1} through gypsum recorded highest plant height of the kernels. However, it was at par to application of sulphur at 30 or 45 ha^{-1} through elemental sulphur and bentonite sulphur

Kumar and Trivedi (2012) reported that the highest seed and straw yields were observed with use of ammonium sulphate which was significantly higher over other sources. The maximum seed and straw yields were recorded with the application of ammonium sulphate followed by gypsum, single super phosphate and pyrite

Makeen *et al*. (2008) reported that number of leaves, plant height and dry matter production per plant were significantly influenced by sulphur application @ 60 kg ha^{-1}. Mustard crop produces higher plant height (Kashved et al., 2010) and primary branches per plant (*Piri et al*., 2011) as compared to the crop grown without S. The source of sulphur (gypsum, bentonite S and pyrite) did not influence the growth parameters of Indian mustard (*Brassica juncea L*.) as reported by Kumar *at el*. (2011).

Singh and Singh (2007) reported that the seed and Stover yields of linseed increased significantly when sulphur was applied through gypsum as compared to the other sources of sulphur. This increase in yield might be attributed to easy availability of SO_4--S present in gypsum as compared to sulphide form in pyrite, which essentially requires its oxidation to be converted into (SO_4)2--S prior to its absorption by the crop

Tomar *et al*. (2007) reported that application of 30 kg sulphur ha^{-1} significantly improved the yield attributes, seed and stover yields of mustard.

(Piri and Sharma, 2006). The increase in seed yield due to S application in mustard was also reported by Piri and Sharma (2006).

Kowalenko (2004) investigated response of forage grass to sulphur applications on coastal British Columbia soil. Gypsum was used as a sulphur fertilizer in the production of winter oilseed rape (*Brassica napus L. var. napus*). Sources of sulphur like gypsum and coaster did not differ significantly with regard to seed and Stover yield of mustard

Jat *et al*. (2003) also reported that sources of sulphur had no significant influence on straw yield of mustard
(Prasad *et al.,* 2002). Powdered elemental S was available to plant sooner than an elemental S fertilizer, but neither as quickly as gypsum. Grain yields of wheat and legumes were increased due to gypsum application (Hamza and Andreson, 2003).

In lentil in the experiment by Singh and Chauhan (2002).
Gypsum application reflected in significant improvement in yield of groundnut

(Rao and Shaktawat, 2002). Among the sources of sulphur, gypsum proved significantly superior with respect to yield attributes (pods plant^{-1} and grain weight), grain and straw yield and harvest index.

Sarmah and Debnath (1999) reported that sulphur fertilization significantly improved most of the yield attributes and seed yield (20.1%) as compared to no sulphur. Application of gypsum and bentonite sulphur indicated their superiority in increasing the seed yield over pyrite. Significantly higher number of branches/plant, siliquae/plant, test weight of seeds, seed yield and stover yield were observed due to application of gypsum or bentonite sulphur as compared to pyrite. Average increase of seed yield over control was 12.9, 29.5 and 32.2% due to application of pyrite, gypsum and bentonite sulphur, respectively. High response to gypsum in respect of seed yield might be due to its readily available $(SO_4)2$--S and high calcium content, whereas pyrite might had further acidifying effect. The difference in seeds/siliqua and seed weight/plant failed to bring any marked change due to use of different sources of sulphur.

Gypsum application (250 kg ha^{-1}) reflected in significant improvement in yield attributes and seed yield of Indian mustard (*Brassica juncea* L.)

Sarmah and Debnath (1999) reported that the difference in plant height of mustard failed to bring any marked change due to use of different sources of sulphur. Gypsum and bentonite sulphur were found to be better source as compared to pyrite.

Singh and Agarwal (1998), gypsum application reflected in better pod length, seeds per pod, grain weight and yield of black gram as compared to other sources of sulphur tested (elemental S, pyrite, gypsum).

The effect of gypsum as a sulphur fertilizer on the yield was tested also on other crops such as sunflower (*Helianthus annuus L.*) (Intodia and Tomar, 1997), cabbage (*Brassica oleracea* L. var. capitata) (Sandreson *et al*., 1996) and cereals (Withers et al., 1995). S source (gypsum and K_2SO_4) did not affect yield of white clover (Moreira et al., 1998).

Biswas *et al*. (1995) reported that application of S fertilizer increased the seed yield of mustard cv. ISN —706. Higher rate of nitrogen application at sowing leads to more rapid leaf area development, prolong the life of' leaves, improves leaf area duration alter flowering and increases overall crop assimilation thus contributing to increased seed yield (Wright *at. al.* 1988). Sulphur (S) is increasingly being recognized as the fourth major plant nutrient after nitrogen, phosphorous and potassium (Jamal *et al*., 2010).

Brassica crops and oilseed rape in particular, are a means of producing high yields of good quality oil for human consumption. Nutritionally oilseed rape and Brassica species in general require sulphur during their growth, for the

synthesis of both protein and naturally occurring glucosinolates (Zhao *et al*., 1993).
There was no noticeable difference in growth between different sources of sulphur (Kalaiyarasan *et al.,* 2003). Sulphur supposed to greatly influence growth attributes mainly leaf area index (Kumar and Yadav, 2007).

Sulphur also plays an important role in the chemical composition of seed. Sulphur increases the percentage of oil content of the seed (Chaudhry *et al*., 1992), glucosinolate content and erucic acid (Marschner, 1986).

Bole and Pittman (1984) found that Rapeseed (*Brassica compestris L.)* required 3 - 10 times more sulphur than barley. Sulphur is involved in the synthesis of chlorophyll and is also required in cruciferae for the synthesis of volatile oil (Marschner, 1986).

The effect of gypsum as sulphur fertilizer on the growth was tested also on other crops such as cereals (Withers *et al*., 1995), cabbage (*Brassica oleracea L*. var. capitata) (Sandreson *et al.,* 1996) and sunflower (*Helianthus annuus L.)* (Intodia and Tomar, 1997).

2.3 Interaction effect of phosphorus and sulphur on the growth and yield of mustard

In Sunflower, a synergistic relationship between P and S was found at relatively low levels.
In the Terai region of Uttar Pradesh, a higher P application standard. With S ha^{-1} weighing 20 kg, in increasing rates of P the relationship was additive but with 40 kg S/ha seed weight went at 60 kg P_2O_5/ha (Gangwar and Paramcswaran. 1976), markedly up Mustard with rapeseed. In pot culture and pot culture, a+ve interaction between P and S was reported (ltautli and everything, 1986) field

trial. S raises the seed yield by 41%, P increase it by 49% and the remaining 10% was due to their synergistic influence (Rauth and Au, 1986).

In experiments on black clay soil of Jabalpur. Madhya Pradesh analyzing 12.5kg available P_20_5 ha and 14.4kg available S /ha. Both the nutrient to exert a strongsynergistic relationship for fahabean nutrition (Nayak and Owivedi, 1990).

In soybeans the combination between P and S was synergistic at 35kg p .

Both positive and negative combination have been reported but recent research has shown that the nature of P-S interaction depends on their rate of application. Several workers have found that the PxS interaction is synergistic at low to medium levels of P and atagonstic only at higher levels, usually at 60 or more Kg P205ha' for field crops. (Ali 1991. Aulakh *et al*.1989.-1990. Pasrieha *et al.* 1987).

An experiment with pigeonpea at Kanke. Bihar also showed the PxS interaction to be rated depended. It was absent at 20-40kg P_20_5 with 20 kg S strongly synergistic at 40-60 kg P_20_5 with 20-40 kg S and tended towards being antagonistic under 60kg P_20_5 + 40kg S /ha. Highest total response (+1150 kg grain/ha) highest synergistic benefit (35%) was obtained from 60 kg P_20_5 +20kg S / ha (AIi 1991).

Ram Baldev and Pareek (2000) conducted an experiment on loamy sand soil of jobner (Rajasthan) to find out the effect of phosphorus and sulphur on yield, oil content and nutrient uptake by mustard. Application of 30 kg P_20_5 / ha recorded significantly higher seed, stover and oil yield and total uptake of N. P and S over control but the N. P and S contents in seed and N and P contents in stover were sigriilicant over control only. Application of 90 kg S / ha being at par with 60 kg S produced significantly higher seed, stover and oil yield and N. P and S contents in seed and stover and their total uptake over control.

Kumar *et al*. (2006) conducted an experiment on Brassica juncca cv. RH-30 under screen house conditions with salinity levels of 0. 8 and 12 ds/m and with the use of phosphorus (20, 40, 60 kg ha^{-1}) and Sulphur (10. 20 and 30 kg / ha) and their combinations (20 kg P/ ha + 10kg S /ha + 40kg P /ha + 20 kg S /ha and 60 kg P/ ha + 30 kg S /ha) 5 after emergence of seedlings. Under saline irrigation, different growth 19 parameters viz dry weight of leaves, leaf area, absolute growth rate, relative growth rate and net assimilation rate exhibited significant decline (ranging from 24 to 73 percent) over non-saline control. Fertilizer applied in combination (60 kg P/ ha + 30 kg S /ha) exhibited higher alleviation (ranging from 24 to 46 percent) of the adverse effect of salinity.

Chapter III

MATERIALS AND METHODS

This chapter includes a brief discussion of the experimental soil, mustard variety, land preparation, experimental design treatments, cultural operations, collection of soil and plant samples etc. and analytical methods followed in the experiment to study the role of P and S on the growth and yield of mustard BARI Sarisha 15 (*Brassica campestris).*

3.1 Experimental site

The research work relating to the study of the role of P and S on the growth and yield of mustard was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka 1207 during the Robi season of 2018-2019.The experimental site was located at 23°46' N latitude and 90° 22' E longitudes with an elevation of 8.2 meter from sea level. The Agro-ecological Zone “AEZ-28” of Madhupur Tract, which falls into Deep Red Brown Terrace Soils. The location of the experimental site has been shown in **Appendix I**

3.2 Climate

The experimental area is situated under the sub-tropical climate and is characterized by less rainfall associated with moderately low temperature during rabi season, October- March and high temperature, high humidity and heavy rainfall with occasional gusty winds during kharif season April-September. Details of the meteorological data of air temperature, relative humidity and rainfall during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e Bangla Nagar (**Appendix V**)

3.3 Soil of the experiment field

The land of the experimental site belongs to the agro-ecological region of “Madhupur Tract” (AEZ No.28). It was Deep Red Brown Terrace soil and belonged to “Nodda” cultivated series. The top soil is clay loam in texture. The content of organic matter was very low (0.78 percent) and soil pH was 5.6. The physical and chemical characteristics of the soil have been presented in **Appendix I and VI**.

3.4 Collection and processing of soil sample

Before land preparation, soil samples were collected from the experimental field to a depth of 0-15 cm from the surface on the basis of the composite sampling process. The collected soil was air dried, ground and passed through a 2-mm sieve and stored in a clean, then dried plastic container for chemical and physical analysis.

3.5 Experimental materials

BARI Sarisha-14, a medium yielding and short duration variety of mustard (*Brassica campestris*) developed by Bangladesh Agricultural Research Institute (BARI), Gazipur was used as experiment crop. The seeds were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur.

Table 3.1 Morphological characteristics of experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Farm, Dhaka
AEZ name	AEZ-28, Madhupur Tract
General soil type	Deep Red Brown Terrace Soil
Soil series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land type	High land

3.6 Treatments of the experiment

Fertilizer treatments consisted of 3 levels of (0, 28 and 36kg P ha^{-1} designated as P_1. P_2, and P_3 respectively) and 3 levels of S (0, 16 and 20 kg S ha^{-1} designated as S_1. S_2 and S_3 respectively).There were 9 treatment combinations. The rates of P and S and their treatment combinations are shown below:

Treatment of the experiment:

Factor A: phosphorus fertilizer (kg/ha).

- P_1- 0 (no phosphorus)
- P_2-28
- P_3-36

Factor B: Sulphur fertilizer (kg/ha)

- S_1- 0 (no sulphur)

- S_2-16
- S_3-20

Treatment combinations

- T1= P_1S_1 (no application of P and S)
- T2= P_1S_2 (0 kg of P+ 16 kg of S)
- T3= P_1S_3 (0 kg of P+ 20 kg of S)
- T4= P_2S_1(28 kg of P+0 kg of S)
- T5= P_2S_2 (28 kg of P+ 16 kg of S)
- T6= P_2S_3 (28 kg of P+ 20 kg of S)
- T7= P_3S_1 (36 kg of P+ 0 kg of S)
- T8= P_3S_2 (36 kg of P+ 16 kg of S)
- T9= P_3S_3 (36 kg of P+ 20 kg of S)

3.7 Experimental design and layout

The experiment was laid out in a Split plot design with three replications. The experimental unit was divided into three blocks each of which representing a replication. There were altogether 27 (9 ×3) unit plots, each plot measuring 3m × 1.5 m. Inter-block and Inter-plot spacing were 0.50 m and 0.75 m, respectively. The layout of the experiment was presented in Appendix VII

3.8 CULTIVATION PROCEDURE

3.8.1 Land preparation

The land of the research field was first opened on November 5, 2018 with a power tiller. One ploughing was done by disc plough followed by two ploughing by tractor drawn cultivator and planking was done invariably after each ploughing to get the fine seed bed. Layout was carefully done as per technical programme of experiment. The land operation was completed on 13 November 2018.

3.8.2 Application of fertilizer

In this experiment fertilizers were used according to BARI and under as follows:

Fertilizers	**Rate of application per ha.**
Urea	120 kg
TSP	As per treatment
MoP	80 kg
Gypsum	As per treatment
ZnO	3 kg
Boric Acid	1.5 kg

The amounts of fertilizer as per treatment in the forms of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid required per plot were calculated. Half 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 was top dressed after 30 days after sowing (DAS).

3.8.3 Seed rate (kg/ha)

Mustard seeds were sown in broadcasting method. The seed rate was used 8 kg ha^{-1}.

3.8.4 Seed Sowing

Sowing was done on 14th November, 2018 in rows 30 cm apart. $^{-}$. 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

3.9 Intercultural operations

One hoeing and hand weeding was done by hand hoe or khurpi after thinning at 45 days after sowing.

3.9.1 Weeding and thinning

Thinning was done in two phases. In the first phase, dense emerging seedlings were uprooted after 10 days of sowing on 27 November 2018. Second phase of thinning and weeding was completed by 20-25 days after sowing on 10 December 2018

3.9.2 Irrigation

Irrigation was done at three times. The first irrigation was given on the post sowing. The second irrigation was given at 15 DAS on 29th November, 2018. The final irrigation was given at the stage of seed formation (50 DAS), on 4th January, 2019.

3.9.3 Pest management

The crop was infested with cutworm at the seedling stage and application of Dursban25EC @ 2.5m1/liter was done twice on January 12 and 20, 2019. The crop was also infested with aphids (*Lipaphis erysimi*) at the time of siliqua filling. The insects were controlled successfully by spraying Ripcord 10 EC @ 3ml/lit water. Special care was taken to protect the crop from birds especially after sowing and germination stages.

3.9.4 Harvesting

The crops was harvested when 80% of the siliquae in terminal raceme turned golden yellow in colour on 20 February 2019. The border rows were harvested first and kept aside. To avoid shattering, harvesting was done in the morning. The harvested crops from each plot were tied into bundles separately and carried to the threshing floor. The crop bundles were sun dried by spreading those on the threshing floor. The seeds were separated from the plants by beating the bundles with bamboo sticks. Thereafter, crop of each net plot was harvested separately and brought to threshing floor after proper tagging.

3.9.5 Threshing and winnowing

The produce of net plot were weighed individually and recorded before threshing. Threshing was done by wooden sticks and seed weight was recorded for net plot after winnowing the produce. To obtain the seed weight was subtracted from the weight of total biomass recorded from each plot.

3.10 General observations of experimental field

The plots under experiment were frequently observed to notice any change in plant growth and other characters were noted down immediately to make necessary measures.

3.10.1 Plant sample

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

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3.10.2 Collection of data

Ten (10) plants from each plot were selected at random and were tagged for the data collection. Data collections were done on the following parameters:

- . Plant height (cm).
- Number of primary branches per plant.
- Number of siliqua per plant.
- Length of siliqua (cm).
- Number of seed per siliqua.
- Thousand seed weight (g).
- Seed yield (ton/ha)
- Stover yield
- Biological yield
- Harvest Index (%)

3.10.2.1 Plant height

The plant height was measured from the ground level to the top of the plant. 10 plants were measured randomly from each plot and averaged. It was done at the ripening stage of the crop.

3.10.2.2 Number of primary branches/plant

Numbers of primary branches were counted at the maximum vegetative stage. 10 plants were selected randomly from each plot and averaged.

3.10.2.3 Number of siliqua /plant

Siliqua were counted at the ripening stage and to plants were selected from each plot and averaged.

3.10.2.4 Length of siliqua

Length of siliqua from each plot were measured randomly after harvest and averaged.

3.10.2.5 Number of seeds/ siliqua

It was done after harvesting. At first, number of seeds / siliqua was counted randomly 10 siliqua were selected and averaged.

3.10.2.6 Weight of thousand seeds

Thousand seed of mustard were counted randomly and then weighed plot wise.

3.10.2.7 Seed yield

Seeds obtained from 1 m^2 area from the center of each unit plot was dried, weighed carefully and then converted into t ha^{-1}

3.10.2.8 Stover yield

The weight of the plants containing grain was taken by subtracting the grain weight from the total weight. The Stover weights were calculated after threshing and separation of grain from the plants of harvested area and then expressed in kg ha^{-1} on dry weight basis.

3.10.2.9 Biological yield

The summation of seed yield and Stover yield were considered as biological yield. Biological yield was calculated by using the following formula,
Biological yield = Seed yield + Stover yield; (dry weight basis).

3.10.2.10 Harvest Index (%)

The harvest index was calculated from the ratio of seed yield to biological yield (Seed yield + Stover yield) and expressed in terms of percentage. The following formula was used for calculating the harvest index-

$$HI = \frac{\text{Economic yield (seed weight)}}{\text{Biological yield (Total dry weight)}} \times 100$$

3.11. Methods for Soil Analysis

3.11.1 Particle size analysis of soil

Particle size analysis of the soil was done by hydrometer method. The textural class was determined using Marshell's Triangular co-ordinate as designated by USDA.

3.11.2 Organic carbon (%)

Soil organic carbon was estimated by Walkley and Black's wet oxidation method as outlined by Jackson (1973).

3.11.3 C/N ratio

The C/N ratio was calculated from the percentage of organic carbon and total N.

3.11.4 Soil organic matter

Soil organic matter content was calculated by multiplying the percent value of organic carbon with the Van Bemmelen factor, 1.724.

% organic matter = % organic carbon × 1.724

3.11.5 Soil pH

The pH of the soil was determined with the help of a glass electrode pH meter using soil: water ratio 1:2.5 (Jackson, 1973).

3.11.6 Total nitrogen (%)

Total nitrogen content in soil was determined by Kjeldahl method by digesting the soil sample with conc. H_2SO_4, 30% H_2O_2 and catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se = 10:1:0.1) followed by distillation with 40% NaOH and by titration of the distillate trapped in H_3BO_3 with 0.01 N H_2SO_4 (Black, 1965).

3.11.7 Available sulphur (ppm)

Available S in soil was determined by extracting the soil samples with 0.15% $CaCl_2$ solution (Page et al., 1982). The S content in the extract was determined turbidimetrically and the intensity of turbid was measured by spectrophotometer at 420 nm wavelength.

3.11.8 Available Phosphorus (ppm)

Available phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ solution, pH 8.5 (Olsen et al., 1954). Phosphorus in the extract was measured spectrophotometrically after development of blue colour (Black, 1965).

3.12 Statistical analysis

The data obtained from the experiment were analyzed statistically to find out the significance of the difference among the treatments. The mean values of all the characters were evaluated and analysis of variance was performed by the 'F' (variance ratio) test. The significance of the differences among pairs of treatment means was estimated by the least significant difference (LSD) test at 5% and 1% level of probability and DMRT was calculated (Gomez and Gomez, 1984).

Chapter IV

RESULTS AND DISCUSSION

The results on different parameters, such that growth parameters, Yield contributing parameters and Yield parameters after harvest of mustard are presented in this chapter.

4.1 GROWTH PARAMETERS

4.1.1 Plant Height

4.1.1.1 Effect of phosphorus on the plant height (cm) of mustard

The effects of phosphorus on the plant height of mustard are presented in Fig-1 Significant variation was observed on the plant height of mustard when the field was fertilized with different doses of phosphorus (**Appendix II**). Among the different doses of phosphorus, P_3 (36 kg P ha^{-1}) showed the highest plant height (74.36 cm). On the other hand, the lowest plant height (62.90 cm) was observed in the P_1 treatment where no phosphorus was applied (**Fig: 1**). Plant height increased with increasing levels of phosphorus. The increased plant height may be due to favorable effects of phosphorus on the vegetative growth of mustard plant.

4.1.1.2 Effect of sulphur on the plant height of mustard

Differences in plant height at all the stages of growth were significant due to different doses of sulphur (**Fig: 2**) (**Appendix II**). Plant height increased with increasing doses of sulphur at all the stages of growth. Sulphur dose @ 16 kg S ha^{-1} exhibited statistical parity with that of 20 kg S ha^{-1} with respect to plant height at all the stages of growth stage. Among the different doses of sulphur, S_2 (16 kg S ha^{-1}) showed the highest plant height (69.11cm). On the other hand, the lowest plant height (67.06 cm) was observed in the S_1 treatment where no sulphur was applied. BARI (1985) reported that the plant height of mustard increased significantly due to the application of S. Singh and Saran (1987) reported that application of 30 kg per ha increase plant height.

4.1.1.3 Interaction effect of phosphorus and sulphur on the plant height of mustard

Combined application of different doses of phosphorus and sulphur fertilizers had significant effect on the plant height of mustard (**Table 4.1**) (**Appendix II**).The lowest plant height (61.17 cm) was observed in the control treatment (no phosphorus and no sulphur). On the other hand, the highest plant height (78.53 cm) was recorded with P_3S_3 (36 kg P ha^{-1} + 20 kg S ha^{-1}). The highest plant height may be due to the positive effects of phosphorus and sulphur on the vegetative growth of the plant

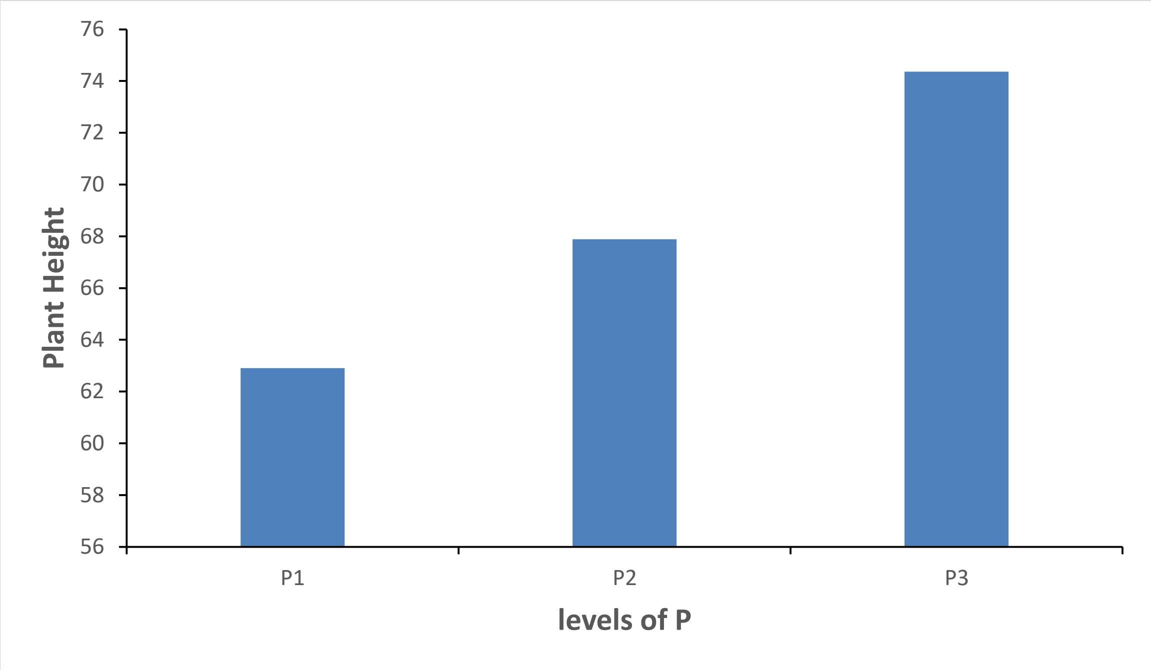

Fig 1: Effect of different levels of phosphorus on plant height (cm) of mustard at harvest

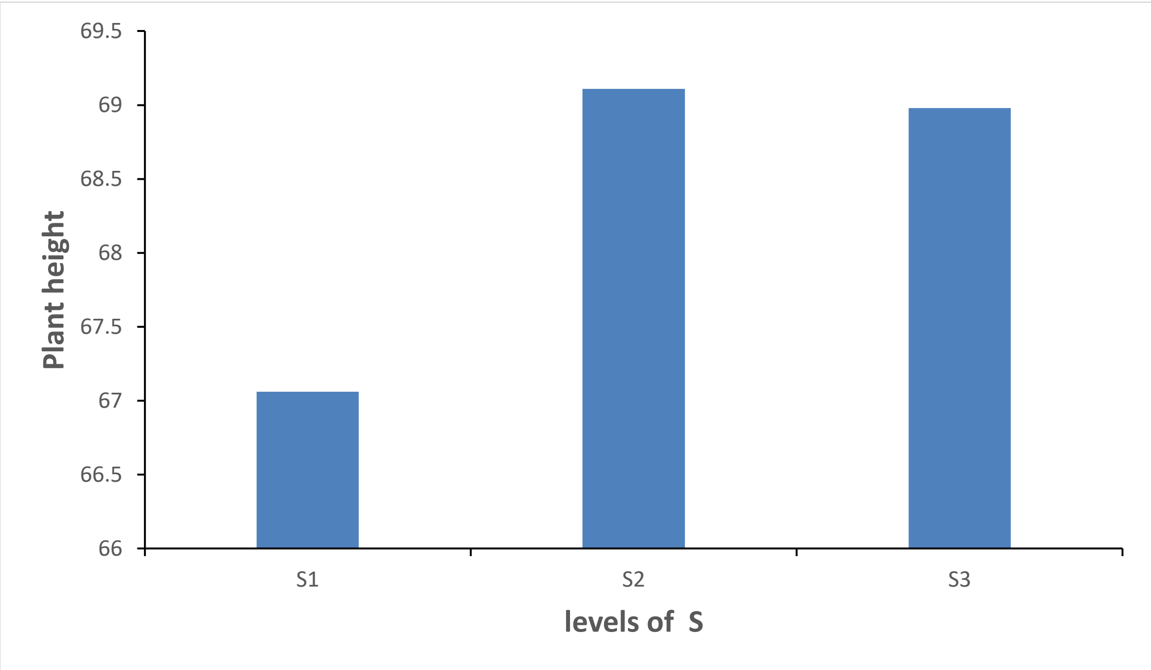

Fig 2: Effect of different levels of sulphur on plant height (cm) of mustard

4.1.2 Number of branches plant^{-1}

4.1.2.1 Effect of phosphorus on the number of branches plant^{-1} of mustard

Insignificant variation was observed in the number of primary branches plant^{-1} of mustard when different doses of phosphorus were applied (**Fig: 3**) (**Appendix III**). The highest number of primary branches plant^{-1} (5.932) was recorded in P_3 (36 kg P ha^{-1}). The lowest number of primary branches plant^{-1} (5.137) was recorded in the P_1 (28 kg P ha^{-1} ha^{-1}) treatment which is statistically similar with P_1 (control) treatment.

4.1.2.2 Effect of sulphur on the number of branches plant^{-1} of mustard

Different treatments of sulphur fertilizer showed insignificant variations in respect of number of primary branches plant^{-1} (**Fig: 4**) (**Appendix III**). Among the different doses of sulphur, S_2 (16 kg S ha^{-1}) showed the highest number of primary branches plant^{-1} (5.232). On the contrary, the lowest number of primary branches plant^{-1} (5.498) was recorded in the S_3 treatment. The decrease number of branches/plant may be due to negative effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the mustard plant.

4.1.2.3 Interaction effect of phosphorus and sulphur on the number of branches plant^{-1} of mustard

Effect of different levels of phosphorous and sulphur showed a statistically significant variation for branches per plant of mustard (**Table 4.1**) (**Appendix III**). The number of branches per plant increased significantly with increasing Phosphorous and sulphur levels. upto the treatment P_3S_3 (36 kg ha^{-1} Phosphorous + 20 kg ha^{-1} Sulphur) and the maximum number of branches per plant was obtained from every growth stages as well as at harvest with this treatment (5.953). Lowest number of branches per plant were also obtained from every growth stage as well as at harvest with this treatment (5.137). Probably 36 kg ha^{-1} Phosphorous + 16 kg ha^{-1} Sulphur ensured the favorable condition for growth of mustard and the ultimate results is the maximum number of branches. The results obtained from the present study was conformity to the findings of Fahmina *et al*. (2013). Mohanti *et al.* (2004) reported similar observations with 30 kg S ha^{-1} application. Dubey *et al*. (1997) reported that S increased the number of primary branches per plant of mustard.

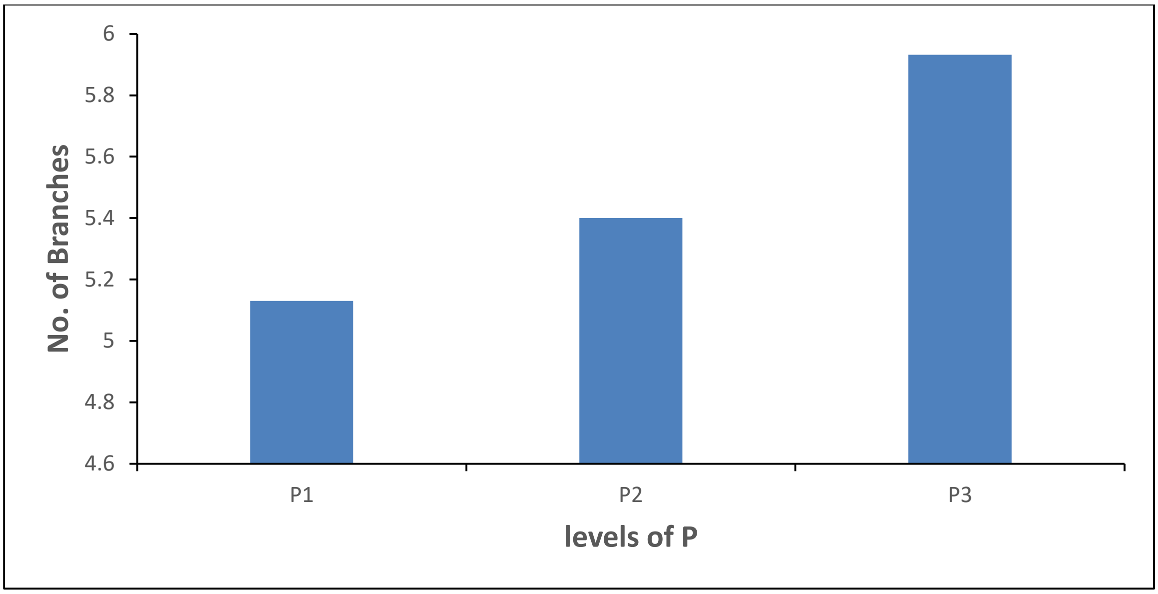

Fig 3: Effect of different levels of phosphorus on number of branches per plant of mustard

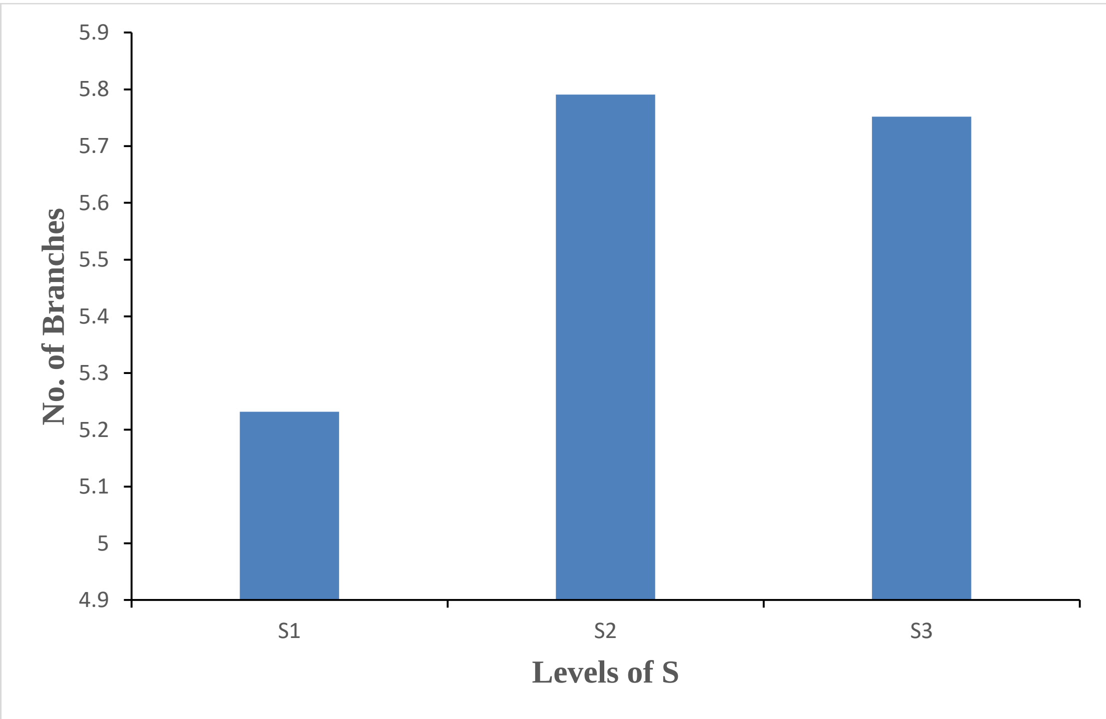

Fig 4: Effect of different levels of sulphur on number of branches per plant of mustard

Table 4.1: Combined effect of different levels of phosphorus and sulphur on plant height (cm), Number of branches per plant of mustard

Treatments	**Plant height(cm)**	**Number of Branches plant^{-1}**
P_1S_1	61.17g	5.467ab
P_1S_2	65.00e	5.863ab
P_1S_3	62.53f	5.137b
P_2S_1	69.80c	5.197ab
P_2S_2	68.00d	5.557ab
P_2S_3	65.87e	5.447ab
P_3S_1	70.20c	5.933a
P_3S_2	74.33b	5.910ab
P_3S_3	78.53a	5.953a
$LSD_{0.05}$	**1.072**	**0.6817**
CV (%)	**0.93%**	**7.24%**

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

P_1: 0 kg P/ha (control) P_2: 28 kg P/ha P_3: 36 kg P/ha

S_1: 0 kg P/ha (control) S_2: 16 kg P/ha S_3: 20 kg P/ha

4.2 YIELD CONTRIBUTING PARAMETERS

4.2.1 Number of siliqua plant^{-1}

4.2.1.1 Effect of phosphorus on the number of siliqua plant^{-1} of mustard

Significant variation was observed in the number of siliqua plant^{-1} of mustard when different doses of phosphorus were applied (**Table 4.2**) (**Appendix II**). The highest number of siliqua plant^{-1} (73.11) was recorded in P (36 kg P ha^{-1}) treatment. The lowest number of siliqua plant-^{1} (55.00) was recorded in the P_1 (control) treatment.

4.2.1.2 Effect of sulphur on the number of siliqua plant^{-1} of mustard

Siliqua plant^{-1} of mustard showed a statistically significant variation for different sulphur levels under this experiment (**Table 4.3**) (**Appendix II**). The number of siliqua plant^{-1} enhanced with increasing the doses of sulphur and the highest and significant number 67.22 was obtained with S_3 (20 kg ha^{-1} sulphur). (Table 4.3) whereas lowest siliqua plant^{-1} was 59.22 and was found in S_1 (control).

Chauhan *et al* (1996) observed that each successive increase in S level from 0 to 50 kg/ha significantly increase the number of siliqua/plant.

4.2.1.3 Interaction effect of phosphorus and sulphur on the number of siliqua plant-^{1} of mustard

The combined effect of different doses of Phosphorus and Sulphur fertilizers on the number of siliqua/plant of mustard was significant (**Table 4.4**) (**Appendix II**). The highest number of siliqua plant-^{1} (75.67) was recorded with the treatment combination of P_3S_3 is (36 kg P ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with P_3S_2 (36 kg P ha + 16 kg S ha^{-1}) treatment. On the other hand, the lowest number of siliqua plant^{-1}(46.67) was recorded in the P_1S_1

treatment. The highest number of siliqua/plant may be due to the fact that, the combined effect of both phosphorus and sulphur played positive effect on the growth and development of mustard plant. Similar results have been observed by Keivanrad and Zandi (2014) on rapeseed in south of Iran.

4.2.2. Length of siliqua plant^{-1}

4.2.2.1 Effect of phosphorus on length of siliqua plant^{-1}of mustard

Significant variation was observed on the length of siliqua plant-1 of mustard when different doses of phosphorus were applied (**Table 4.2**) (**Appendix II**). The highest siliqua length (5.989 cm) obtained from P_3 (36 kg of P ha^{-1}) and lowest (4.767) from P_1 treatment.

4.2.2.2 Effect of sulphur on the length of siliqua plant of mustard

A perusal of data presented in **Table 4.3** revealed that the effect of sources of sulphur on length of siliqua was found not significant at harvest stage of the crop (**Appendix II**).Though S exhibited maximum length of siliqua (5.433) rather than remaining doses of sulphur at harvest and other stages. Chauhan *et al* (1996) observed that each successive increase in S level from 0 to 50 kg per ha significantly increase the number of siliqua per plant.

4.2.2.3 Interaction effect of phosphorus and sulphur on the length of siliqua/ plant of mustard

The combined effect of different doses of P and S fertilizers on the length of siliqua plant^{-1} of mustard was significant (**Table 4.4**) (**Appendix II**).The highest length of siliqua plant^{-1} (6.267 cm) was recorded with the treatment combinations of P_3S_3 and the lowest length of siliqua plant^{-1} (4.700 cm) was recorded with the treatment combinations of P_1S_1.

4.2.3 Number of seed/siliqua

4.2.3.1 Effect of phosphorus on the number of seed siliqua^{-1} of mustard

Significant variation was observed in the number of seed siliqua^{-1} of mustard when different doses of phosphorus were applied (**Table 4.2**) (**Appendix III**).The highest number of seed siliqua^{-1} (45.33) was recorded in P_3 (36 kg P ha^{-1}) treatment. The lowest number of seed siliqua^{-1} (33.67) was recorded in the P1 (control) treatment. The number of seed siliqua^{-1} did not increase with increasing levels of phosphorus up to certain level.

4.2.3.2 Effect of sulphur on the number of seed siliqua^{-1}of mustard

siliqua plant^{-1}of mustard showed a statistically significant variation for different sulphur levels under this experiment (**Table 4.3**) (**Appendix III**). The number of siliqua plant^{-1} enhanced with increasing the doses of sulphur and the highest and significant number 41.11 was obtained with S_3 (20 kg ha^{-1} sulphur).) Whereas lowest siliqua plant^{-1} was 37.00 and was found in S1 (control). Mondal and Gaffer (1983) and Gaffer and Razzaque (1983) also reported the similar findings from their experiment.

4.2.3.3 Interaction effect of phosphorus and sulphur on the of number of seed siliqua-1 of mustard

The combined effect of different doses of P and S fertilizers on the number of seed siliqua^{-1} of mustard was significant (**Table 4.4**) (**Appendix III**).The highest number of seeds plant^{-1} (49.00) was recorded with the treatment combination of P_3S_3 (36 kg P ha^{-1}+ 20 kg S ha^{-1}) which were statistically similar with all other treatment combinations. Whereas lowest siliqua plant^{-1} was 29.67 and was found in P_1S_1 (control).

4.2.4. Weight of 1000 seed (g)

4.2.4.1 Effect of phosphorus on the weight of 1000 seed of mustard

Significant variation was observed on the weight of 1000 seed of mustard when different doses of phosphorus were applied (**Table 4.2**) (**Appendix III**).The highest weight of 1000 seed (3.081 g) was recorded in P_3 (36 kg P ha^{-1}) treatment. The lowest weight of 1000 seed (2.601 g) was recorded in the P_1 treatment. The increased seed weight may be due to the favourable effects of phosphorus on the vegetative growth that helped proper growth and development of the mustard seed.

4.2.4.2 Effect of sulphur on the weight of 1000 seed weight (g) of mustard

Different level of sulphur exhibited statistically significant variation for 1000 seed weight (**Appendix III**). It increased significantly with higher levels of S with the highest (2.953 g) at S_3 treatment comprising of 20 kg S/ha which was statistically similar (2.890 g) with treatment S_2 comprising of 16 kg S/ha (**Table 4.3**). Chauhan *et al* (1996) observed that each successive increase in S level from 0 to 50 kg per ha significantly increase the number of siliqua per plant.

4.2.4.3 Interaction effect of phosphorus and sulphur on the weight of 1000 seed of Mustard

Interaction effect of nitrogen and sulphur showed a significant variation for 1000 seed weight under the present experiment (**Appendix III**). The highest weight of 1000 seed (3.257g) was recorded from the treatment combination P_3S_3 comprising of 36 kg P/ha + 20 kg S/ha and the lowest (2.340 g) was recorded from P_1S_1 where no phosphorous and sulphur were applied (**Table 4.4**).

Table 4.2: Effect of different levels of phosphorus on number of siliqua per plant, Length of siliqua (cm**),** number of seed per siliqua and thousand seed weight of mustard.

Treatments	**Number of siliqua plant^{-1}**	**Length of siliqua(cm)**	**Number of seeds siliqua^{-1}**	**1000 seed weight**
P_1	55.00 c	4.767 c	33.67 c	2.601 c
P_2	62.67 b	5.244 b	39.44 b	2.874 b
P_3	73.11 a	5.989 a	45.33 a	3.081 a
$LSD_{0.05}$	**1.977**	**0.1061**	**1.677**	**0.0969**
CV (%)	**3.21%**	**2.05%**	**4.38%**	**0.94%**

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

P_1: 0 kg P/ha (control) P_2: 28 kg P/ha P_3: 36 kg P/ha

Table 4.3: Effect of different levels of sulphur on number of siliqua per plant, Length of siliqua (cm**),** number of seed per siliqua and thousand seed weight of mustard.

Treatments	**Number of siliqua plant^{-1}**	**Length of siliqua(cm)**	**Number of seeds siliqua^{-1}**	**1000 seed weight**
S_1	59.22 c	5.233 b	37.00 b	2.713 b
S_2	64.33 b	5.333 ab	40.33 a	2.890 a
S_3	67.22 a	5.433 a	41.11 a	2.953 a
$LSD_{0.05}$	**1.977**	**0.1061**	**1.677**	**0.0969**
CV (%)	**3.21%**	**2.05%**	**4.38%**	**0.94%**

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

S_1: 0 kg P/ha (control) S_2: 16 kg P/ha S_3: 20 kg P/ha

Table 4.4: Combined effect of different levels of phosphorus and sulphur on number of siliqua per plant, Length of siliqua (cm**),** number of seed per siliqua and thousand seed weight of mustard.

Treatments	**Number of siliqua plant^{-1}**	**Length of siliqua(cm)**	**Number of seeds siliqua^{-1}**	**1000 seed weight**
P_1S_1	46.67e	4.700f	29.67e	2.340 e
P_1S_2	61.00c	4.900e	36.00d	2.713 d
P_1S_3	57.33d	4.700f	35.33d	2.750 cd
P_2S_1	62.00c	5.200d	39.33c	2.873 cd
P_2S_2	66.00b	5.500c	40.00c	2.897 bcd
P_2S_3	60.00cd	5.033de	39.00c	2.853 cd
P_3S_1	69.00b	5.800b	42.00c	2.927 bc
P_3S_2	74.67a	5.900b	45.00b	3.060 b
P_3S_3	75.67a	6.267a	49.00a	3.257 a
$LSD_{0.05}$	**3.424**	**0.1839**	**2.905**	**0.1678**
CV (%)	**3.21%**	**2.05%**	**4.38%**	**0.94%**

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

P_1: 0 kg P/ha (control) P_2: 28 kg P/ha P_3: 36 kg P/ha

S_1: 0 kg P/ha (control) S_2: 16 kg P/ha S_3: 20 kg P/ha

4.3 YIELD PARAMETERS

4.3.1 Seed Yield (t/ha)

4.3.1.1 Effect of phosphorus on the seed yield of mustard

Application of phosphorous at different level showed a statistically significant variation for seed yield per hectare of mustard under the present trial (**Appendix IV**) With increasing the levels of phosphorous, the seed yield increased significantly up to 36 kg P/ha. However, the seed yield decreased significantly with the application of 28 kg P/ha (S_2) compared to 36 kg P/ha. The highest seed yield (2.711 t/ha) (**Table: 4.5)** was recorded from P_3 treatment comprising of 36 kg P/ha which was closely followed (2.423 t/ha) with P_2 and the lowest seed yield (1.859 t/ha) was recorded from P_1 treatment (control).

4.3.1.2 Effect of sulphur on the seed yield (t/ha) of mustard

Application of sulphur at different level showed statistically significant differences for seed yield per hectare (**Appendix IV**). The application of S favored the seed yield of mustard up to the highest level (20 kg S/ha). The highest seed yield (2.480 t/ha) was recorded from S_3 treatment comprising of 20kg S/ha (**Table 4.6).** On the other hand the lowest seed yield (2.202 t/ha) was recorded from the S_1 treatment (control). Banueles *et al*. (1990) recorded significant differences for different level of sulphur application.

4.3.1.3 Interaction effect of phosphorus and sulphur fertilizers on the seed yield

Significant interaction effect was also recorded between phosphorous and sulphur for seed yield per hectare under the present experiment (**Appendix IV**).

The highest yield (2.807 t/ha) was recorded from the treatment combination P_3S_3 comprising of 36 kg S/ha + 20 kg S/ha which is statistically similar with the treatment P_3S_2 and P_3S_1. On the other hand, the lowest (1.540 t/ha) was recorded from P_1S_1 where no phosphorous and sulphur was applied (**Table 4.7**).

4.3.2 Stover yield

4.3.2.1 Effect of phosphorus on the Stover yield of mustard

Application of phosphorous at different level showed a statistically significant variation for shoot yield per hectare of mustard under the present trial (**Appendix IV**). With increasing the levels of phosphorous, the shoot yield increased significantly up to 36 kg P/ha. However, the shoot yield decreased significantly with the application of 28 kg P/ha (P_3) compared to 36 kg P/ha. The highest shoot yield (2.754 t/ha) (**Table: 4.5**) was recorded from P_3 treatment comprising of 36 kg P/ha and the lowest shoot yield (2.063 t/ha) was recorded from P_1 treatment (control).

4.3.2.2 Effect of Sulphur on the Stover yield of mustard

Application of sulphur at different level showed statistically significant differences for shoot yield per hectare (**Appendix IV**). The application of S favored the shoot yield of mustard up to the highest level (20 kg S/ha). The highest shoot yield (2.609 t/ha) was recorded from S_3 treatment comprising of 20 kg S/ha (**Table 4.6**). On the other hand the lowest shoot yield (2.379 t/ha) was recorded from the S0 treatment (control). Banueles et al. (1990) recorded significant differences for different level of sulphur application.

4.3.2.3 Interaction effect of phosphorus and sulphur fertilizers on the Stover yield

Significant interaction effect was also recorded between phosphorus and sulphur for shoot yield per hectare under the present experiment (**Appendix IV**). The highest shoot yield (2.917 t/ha) was recorded from the treatment combination P_3S_3 comprising of 36 kg P/ha + 20 kg S/ha and the lowest (1.850 t/ha) was recorded from P_1S_1 where no nitrogen and sulphur was applied (**Table 4.7).**

4.3.3 Biological Yield (t/ha)

4.3.3.1 Effect of phosphorus on the Biological yield of mustard

Biological yield of mustard was significantly different at different level of phosphorus (**Table 4.5**) **(Appendix IV)**. The results under the present study indicated that the treatment P_3 (36 kg ha^{-1} Phosphorous) produced maximum biological yield of 5.402 t ha^{-1}. The lowest biological yield of 3.922 t ha^{-1} was found with the treatment P_1 (control).

4.3.3.2 Effect of sulphur on the Biological yield of mustard

Sulphur had significant influence on the biological yield of mustard (**Table 4.6**). The highest biological yield of 5.001 t ha^{-1} was found from S_3 (20 kg/ha) On the other hand, the lowest biological yield of 4.581 t ha^{-1} was found from P_1 (control). The result obtained from the present study was similar with the findings of Singh *et al.* (1986).

4.3.3.3 Interaction effect of phosphorus and sulphur fertilizers on the biological yield

Biological yield was significantly influenced by the interaction effect of Phosphorus and sulphur level (**Appendix IV**). Results showed that the maximum biological yield of 5.483 t ha^{-1} was found from the interactions of P_3S_3 (36 kg ha^{-1} phosphorus + 20 kg ha^{-1}sulphur). On the other hand, the lowest biological yield 3.390 t/ha (**Table: 4.7**) was found from the treatment combination of P_1S_1 (0 kg ha^{-1} phosphorus + 0 kg ha^{-1} sulphur). From this study it suggests that proper combination of P and S increases biological yield

4.3.4. Harvest index (%)

4.3.4.1 Effect of phosphorous on harvest index (%) of mustard

Harvest index **(Appendix IV)** is an important attribute 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). Harvest index may be termed as the ratio of economic yield to biological yield**.** Harvest index (%) of mustard was significantly different at different level of phosphorous (**Table 4.5**). The table shows that the treatment P_3 (36 kg ha^{-1}) produced maximum harvest index of 50.18 %.The lowest harvest index of 46.84 % was found with the treatment P_1 (control).

4.3.4.2 Effect of sulphur on harvest index (%) of mustard

Sulphur had significant influence on the harvest index (**Table 4.28**) (**Appendix IV**). It was observed that the highest harvest index of 49.64 % was found from S_2 (16 kg ha^{-1}). On the other hand, the lowest harvest index of 46.91% (Table: 4.6) was found from S_1 (control). The result obtained from the present study was similar with the findings of Scarisbric *et al*. (1982) and Sharif *et al.* (1990).

4.3.4.3 Interaction effect of phosphorus and sulphur fertilizers on the harvest Index (%)

Harvest index (%) was not significantly influenced by the interaction effect of phosphorous and sulphur level (**Table 4.7**) (**Appendix IV**). Numerically the highest harvest index (%) of 51.18 was found from the interactions of P_3S_3 (36 kg ha^{-1} phosphorous + 20 kg ha^{-1} sulphur). On the other hand, the lowest harvest index (%) of 45.40 was found from the treatment combination of P_1S_1 (control).

Table 4.5: Effect of different levels of phosphorus on Seed yield, Stover yield (t/ha), Biological yield (t/ha), Harvest index (%) of mustard

Treatments	**Seed Yield (t/ha)**	**Stover yield (t/ha)**	**biological yield(t/ha)**	**Harvest Index (%)**
P_1	1.859 c	2.063 c	3.922 c	46.84 b
P_2	2.423 b	2.691 b	5.178 b	47.28 b
P_3	2.711 a	2.754 a	5.402 a	50.18 a
$LSD_{0.05}$	**0.1370**	0.04333	**0.05307**	0.8165
CV (%)	**1.93%**	1.59%	**1.10%**	**1.75**

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

P_1: 0 kg P/ha (control) P_2: 28 kg P/ha P_3: 36 kg P/ha

Table 4.6: Effect of different levels of sulphur on Stover yield (t/ha), Biological yield (t/ha), Harvest index (%) of mustard

Treatments	**Seed Yield (t/ha)**	**Stover yield(t/ha)**	**Biological yield(t/ha)**	**Harvest Index (%)**
S_1	2.202 b	2.379 c	4.581 c	46.91 c
S_2	2.311 b	2.521 b	4.920 b	49.64 a
S_3	2.480 a	2.609 a	5.001 a	47.75 b
$LSD_{0.05}$	**0.1370**	0.04333	0.05307	0.8165
CV (%)	**1.93%**	1.59%	**1.10%**	**1.75**

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

S_1: 0 kg P/ha (control) S_2: 16 kg P/ha S_3: 20 kg P/ha

Table 4.7: Combined effect of different levels of phosphorus and sulphur on Seed yield, Stover yield (t/ha), Biological yield (t/ha), Harvest index (%) of mustard

Treatments	**Seed Yield (t/ha)**	**Stover yield**	**Biological Yield(t/ha)**	**Harvest Index (%)**
P_1S_1	1.540 d	1.850 g	3.390 f	45.40 ef
P_1S_2	2.083 c	2.043 f	4.127 e	50.48 ab
P_1S_3	1.953 c	2.297 e	4.250 d	45.96 de
P_2S_1	2.390 b	2.503 d	4.893 c	48.84 c
P_2S_2	2.550 ab	2.843 ab	5.393 a	47.27 d
P_2S_3	2.330 b	2.613 c	5.247 b	44.41 f
P_3S_1	2.677 a	2.783 b	5.460 a	49.02 bc
P_3S_2	2.650 a	2.677 c	5.263 b	50.35 ab
P_3S_3	2.807 a	2.917 a	5.483 a	51.18 a
$LSD_{0.05}$	**0.2374**	**0.07506**	**0.09193**	1.414
CV (%)	**1.93%**	**1.59**	**1.10**	**1.75%**

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

P_1: 0 kg P/ha (control) P_2: 28 kg P/ha P_3: 36 kg P/ha

S_1: 0 kg P/ha (control) S_2: 16 kg P/ha S_3: 20 kg P/ha

Chapter V

SUMMARY AND CONCLUSION

The experiment was conducted at the field of Sher-e-Bangla Agricultural University farm, Dhaka, Bangladesh during the period from November 2018 to February 2019 to determine the effect of phosphorous and sulphur with different population density on growth and yield of mustard (BARI Sharisa-14).

Two factors Randomized Complete Block Design was followed with 27 treatment combinations having unit plot size of 3m x 1.5m (4.5 m^2) and replicated thrice. Two factors were phosphorus and sulphur. The treatments were P_1S_1 (no application of P and S) , P_1S_2 (0 kg of P+ 16 kg of S), P_1S_3 (0 kg of P+ 20 kg of S), P_2S_1(28 kg of P+0 kg of S), P_2S_2 (28 kg of P+ 16 kg of S), P_2S_3 (28 kg of P+ 20 kg of S), P_3S_1 (36 kg of P+ 0 kg of S), P_3S_2 (36 kg of P+ 16 kg of S), P_3S_3 (36 kg of P+ 20 kg of S).

Recommended doses of N, K, Zn and B (120 kg N from urea, 40 kg K from MOP, 3 kg Zn from ZnO and 1 kg B ha^{-1} from Boric acid, respectively) were applied.

The whole required amounts of MOP, ZnO, Boric acid and half of the urea fertilizer were applied as basal dose during final land preparation. The remaining half of urea was top dressed after 22 days of germination. The required amounts of P (from TSP) and S (from gypsum) were applied at a time as per treatment combination after land preparation were mixed properly through hand spading. All the data were statistically analyzed following F-test and the mean comparison was made by DMRT.

The results of the experiment are stated below:

The combined effect of P and S showed positive effect on the plant height, number of primary branches per plant, number of siliqua per plant, length of siliqua, number of seeds per siliqua, thousand seed weight (g), seed yield (t ha^{-1}), stover yield(t/ha), biological yield(t/ha) and harvest index(%) . All the plant characters increased with increasing levels of P and S up to certain level.

Plant height was significantly influenced by different levels of combined application of P and S. Plant height increased with increasing levels of P and S up to certain level. The tallest plant (78.53 cm) was found in P_3S_3 treatment, which was higher over control treatment (61.17 cm). Number of siliqua per plant was found maximum (75.67) in P_3S_3 and minimum (46.67) in P_1S_1treatment. Number of branches per plant insignificantly varied with different characters. Number of seed per siliqua, length of siliqua, weight of thousand seed, seed yield, Stover yield(t/ha), biological yield(t/ha) and harvest index(%) were highest in P_3S_3 (49.00), P_3S_3 (6.267), P_3S_3(3.257g), P_3S_3 (2.807 ton/ha), P_3S_3 (2.917 t/ha), P_3S_3 (5.48 t/ha) and P_3S_3 (51.18 %) respectively and the lowest was recorded in P_1S_1 (17.32), (6.27 cm), (2.31 gm), (1.54 ton/ha), (1.850), (3.390 t/ha) and (45.40 %) respectively.

No or small significant variation was observed due to the individual effect of P and S on mustard growth and yield attributing characters. The individual application of P @ 36 kg ha^{-1} (P_3) produced the tallest plant (74.36cm), whereas application of P and S produced no significant variation in number of primary branches. The remaining character such as number of siliqua per plant, length of siliqua number of seeds per siliqua, thousand and seed yield (t/ha) showed highest result in P 36 (45.33), (5.989 cm), (3.081), (2.71) ton/ha respectively. On the other hand, the individual application of S @ 20 kg ha^{-1} (P_3) produced the tallest plant (74.36cm), whereas application of P and S produced no significant variation in number of primary branches. The remaining character such as number of siliqua per plant, length of siliqua number of seeds per siliqua, thousand and seed yield (t/ha) showed highest result in S_3 (45.33), (5.989 cm), (3.081),(2.711 ton/ha)

Like all other plant characters, seed yield of mustard was influenced significantly due to combined application of P and S. Seed yield was increased with increasing levels of P and S up to certain level. The highest seed yield of mustard (2.807 t ha^{-1}) was recorded in P_3S_3 treatment. The lowest yield (1.54 t ha^{-1}) was recorded in P_1S_1 treatment. Combined application of P @ 36 kg ha^{-1} and S @ 20 kg ha^{-1} produced higher seed yield compared to control treatment significantly. The combined application of P and S had positive effect on seed yield of mustard.

From the results of the present experiment, it may be concluded that significantly higher growth and yield performance of mustard was observed in the P_3S_3 treatment where 36 kg P ha^{-1} and 20 kg S ha^{-1} were applied.

However, this result has made a basis for further study that in different regions involving different factors of production of mustard to make a specific conclusion. Further research is, therefore, necessary to reach a conclusion.

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

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh to investigate regional adaptability and other performances;

2. Further study may be conducted by using different levels of S and P fertilizer.

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APPENDICES

Appendix I: Map showing the experimental site under study

Appendix II : Analysis of variance (mean square) of the data for Plant Height(cm), Length of Siliqua(cm), Number of seed/siliqua, No. of branch/plant on mustard.

Source of variation	**df**	PH	SL	S/S
Replication	**2**	0.401	0.001	10.037
Factor A	2	296.905	3.414	306.259
Factor B	2	11.907	0.090	42.926
Factor AB	4	31.566	0.149	15.593
Error	16	0.408	0.012	2.995

Appendix III: Analysis of variance (mean square) of the data for No. of seed /plant of Mustard, 1000 seed weight (g).

Source of variation	**Df**	NB	**NS/S**	**1000SW**
Replication	**2**	0.023	6.037	0.001
Factor A	2	0.732	743.815	0.522
Factor B	2	0.231	147.704	0.139
Factor AB	4	0.135	42.704	0.050
Error	16	0.165	4.162	0.001

Appendix IV: Analysis of variance (mean square) of the data for yield (t/ha), Stover Yield (t/ha), Biological yield (t/ha), Harvest Index (%) of Mustard.

Source of variation	Df	SY	St. Y	BY	HI
Replication	**2**	0.001	0.003	0.001	1.242
Factor A	2	1.692	1.314	5.726	29.730
Factor B	2	0.176	0.121	0.447	17.686
Factor AB	4	0.063	0.099	0.222	12.124
Error	16	0.002	0.002	0.003	0.710

Appendix V. temperature, Relative Humidity and Total rainfall of the experimental site during the period from November 2018 to February 2019.

Month	Air Temperature (o C)			Relative humidity (%)	Total rainfall (mm)
	maximum	minimum	Mean		
November	28.50	8.52	18.56	56.75	14.40
December	28.50	6.70	16.10	54.80	0.0
January	23.70	11.70	17.75	46.20	0.0
February	22.75	14.26	18.51	36.80	0.0

Monthly average of air

Source: Bangladesh Meteorological Department, Climate Division, Agargoan, Dhaka.

Appendix VI. Physical and chemical properties of the initial soil

Particle size analysis of soil	**Sand (%)**	**29.80**
	Silt (%)	39.1
	Clay (%)	31.1
Texural class		Clay loam
PH		5.7
Total N (%)		0.079
Organic matter (%)		1.07
Available phosphorous (ppm)		31.5
Available potassium(me/100gm soil)		0.16
Available sulphur (mg kg^{-1})		13
Available Zinc(mg/g soil)		4.78

Source: Soil Resource Development Institute (SRDI), Khamarbari, Farmgate , Dhaka

Appendix VII: Layout of the experimental field

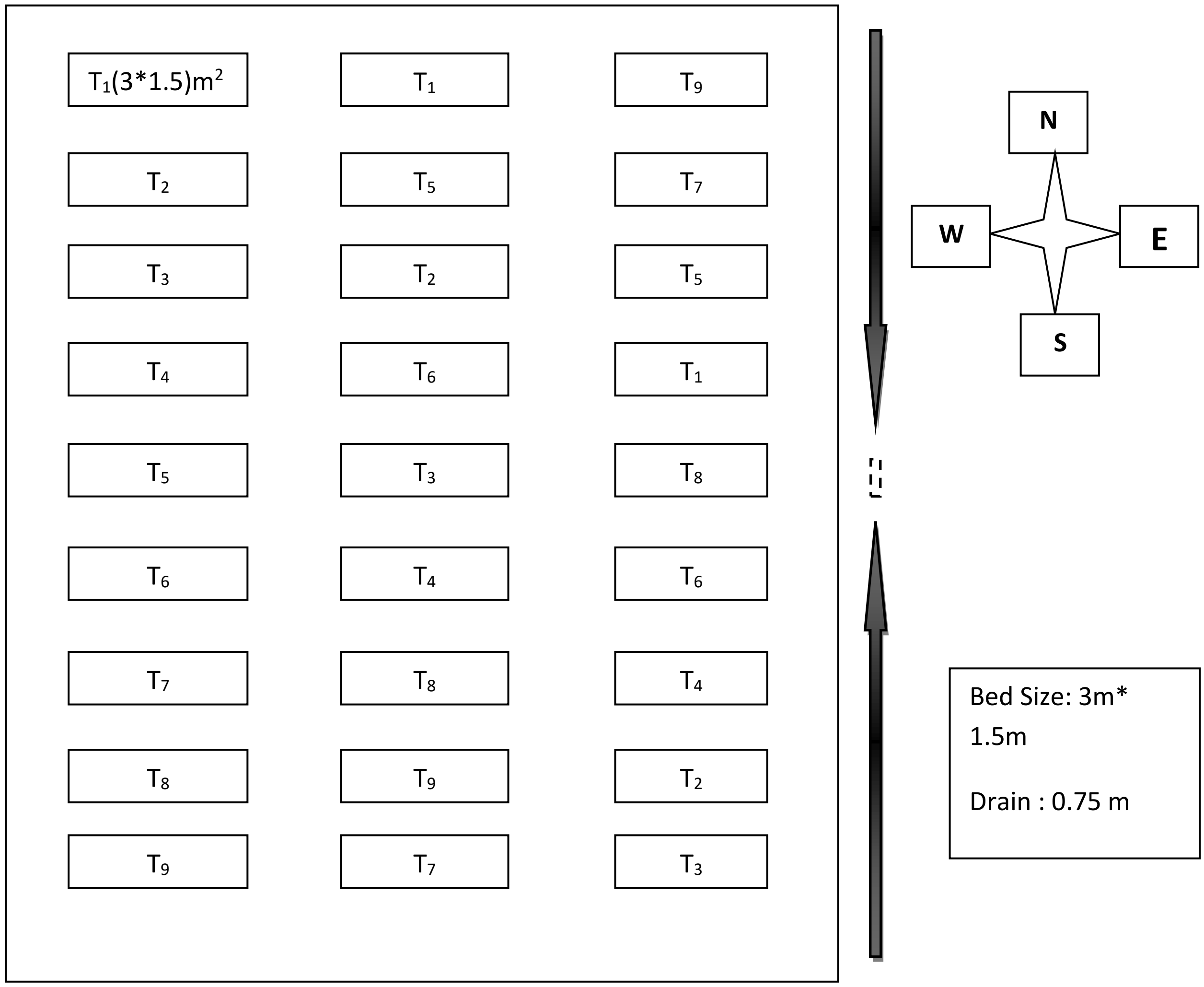

Fig: layout of the experimental site