ROLE OF PHOSPHORUS AND SULPHUR ON THE GROWTH, CHEMICAL COMPOSITION, YIELD AND OIL CONTENT OF MUSTARD (SAU SHARISHA-1)

By

TAMANNA YASMIN
REGISTRATION NO. 09-03737

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APPROVED BY:

(Prof. Dr. Md. Nurul Islam)
Dept. of Soil Science
SAU, Dhaka
Supervisor

(Prof. Dr. Md. Asaduzzaman Khan)
Dept. of Soil Science
SAU, Dhaka
Co-supervisor

Pᴃof. Mst. Afrose Jahan
Dept. of soil Science
SAU, Dhaka
Chairman
Examination Committee

DEPARTMENT OF SOIL SCIENCE

Sher-e-Bangla Agricultural University

Sher-e-Bangla Nagar, Dhaka-1207

Memo No: SAU/Soil Science/

CERTIFICATE

This is to certify that the thesis entitled "**ROLE OF PHOSPHORUS AND SULPHUR ON THE GROWTH, CHEMICAL COMPOSITION, YIELD AND OIL CONTENT OF MUSTARD (SAU SHARISHA-1)**" submitted to the ***DEPARTMENT OF SOIL SCIENCE***, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of ***MASTER OF SCIENCE IN SOIL SCIENCE***, embodies the results of a piece of bonafide research work carried out by ***TAMANNA YASMIN***, *Registration number: 09-03737* under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated:
Dhaka, Bangladesh

Prof. Dr. Md. Nurul Islam
Department of Soil Science
Sher-e-Bangla Agricultural University
Dhaka-1207

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The Author

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 2010 to March 2011 to study the role of phosphorus and sulphur on the growth, yield and oil content of mustard (SAU Sharisha-1). The experimental soil was clay loam in texture having pH of 5.8. The experiment included four levels of phosphorus viz., 0, 20, 40 and 60 kg P ha^{-1} and four levels of sulphur viz., 0, 15, 30 and 50 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 @ 60 kg ha^{-1} produced the highest seed yield, plant height, number of primary branches $plant^{-1}$, number of siliqua $plant^{-1}$, 1000-seed weight. Sulphur fertilizer also had significant effect on yield and yield attributes of mustard. Application of sulphur @ 15 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 thousand seed, seed yield was found highest in the treatment combination $P_{60}S_{50}$, $P_{40}S_{15}$, $P_{60}S_{30}$, P_0S_{50}, $P_{60}S_0$, $P_{60}S_{15}$ respectively. The oil and protein content was found highest in $P_{60}S_{30}$ and $P_{20}S_{30}$. 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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INTRODUCTION

CHAPTER I

INTRODUCTION

Mustard is the most important and dominant crop in Bangladesh and occupies an area of 72,000 hectares land and produces about 74,000 metric tons of oilseeds. The production rate of mustard is 356.00 kg/acre in Bangladesh (BBS 2008). Among the oil seed crops mustard is the main cultivable edible oilseed crop of Bangladesh and its performance in total oilseed production is approximately 70 percent. Annual requirement of edible oil is 5 lakh metric tons. That is, the internal production of edible oil can meet up only less than one-third of the annual requirement (Mondal and Wahhab, 2001).

Mustard is one of the most important oilseed crop throughout the world after soybean and groundnut (FAO, 2004). It has a remarkable demand as edible oil in Bangladesh. It occupies first position of the list in respect of area and production among the oilseed crops grown in this country (BBS, 2004). Mustard seed contain 40-45% oil and 20-25% protein (Mondal and Wahab, 2001). Using local ghani average 33% oil may be extracted. Oil cake is a nutritious food item for cattle and fish. Oil cake is also used as a good organic fertilizer. Dry mustard plants may be used as fuel.

In Bangladesh oilseed crops play a vital role in human nutrition. It is not only a rich source of energy (about 9 kcal/gm) but also rich in soluble vitamins viz. A, D, E and K. The national nutrition council (NCC) of Bangladesh reported that recommended dietary allowance (RDA) per capita per day should be 6 gm of oil for a diet with 2700 kcal (USDA, 2011).

Mustard is grown for the production of vegetable oil for human consumption, animal feed and biodiesel. From time immemorial rapeseed oil plays an important role as a fat substitute in our daily diet. This is widely used as cooking ingredients. Bangladesh has been in short of 65 to 70% of the demand of the edible oil. As a result, a huge amount of foreign currency is being drained out every year for importing oil and oilseed from abroad. Mustard oil's proponents claim that it is one of the most heart-healthy oils and has been reported to reduce cholesterol levels, lower serum tryglyceride levels, and keep platelets from sticking together. Rapeseed produces great amounts of nectar, and honeybees produce a light colored, but peppery honey from it. It must be extracted immediately after processing is finished, as it will quickly granulate and will be impossible to extract (Gordon, 2003).

Seed is the valuable, harvested component of the mustard crop. The plant is ploughed back in the soil or used as bedding. Some ecological or organic operations, livestock such as sheep or cattle are allowed to graze on the plants. Rapeseed "oil cake" is used as a fertilizer. Processing of rapeseed for oil production provides rapeseed animal meal as a by-product. The by-product is a high-protein animal feed, competitive with soya. The feed is mostly employed for cattle feeding, but also for pigs and chickens . The meal has a very low content of the glucosinolates responsible for metabolism disruption in cattle and pigs (USDA, 2011). Rapeseed oil is also used in the manufacture of biodiesel for powering motor vehicles. Formerly, owing to the costs of growing, crushing, and refining rapeseed biodiesel, rapeseed derived biodiesel cost more to produce than standard diesel fuel. Rapeseed oil is the preferred oil stock for biodiesel production in most of Europe, accounting for about 80% of the feedstock (Anonymous, 2011).

Leading producers of mustard include the European Union, Canada, the United States, Australia, China and India. In India, it is grown on 13% of cropped land. According to the United States Department of Agriculture, mustard was the third leading source of vegetable oil in the world in 2000, after soybean and oil palm, and also the world's second leading source of protein meal, although only one-fifth of the production of the leading soybean meal. World production is growing rapidly, with FAO reporting that 36 million tonnes of mustard was produced in the 2003-2004 season and estimates of 58.4 million tonnes in the 2010-2011 seasons (USDA, 2011). Worldwide production of mustard has increased sixfold between 1975 and 2007. The present situation of mustard production is shown in the Table 1.1.

Table 1.1: Top rapeseed producers

(million metric tons)

Country	**2000**	**2005**	**2007**	**2009**
China	11.3	13.0	10.5	13.5
Canada	7.2	9.4	9.6	11.8
India	5.8	7.6	7.4	7.2
Germany	3.6	5.0	5.3	6.3
France	3.5	4.5	4.7	5.6
Poland	1.0	1.4	2.1	2.5
United Kingdom	1.2	1.9	2.1	2.0
Australia	1.8	1.4	1.1	1.9
Ukraine	0.1	0.3	1.0	1.9
Czech Republic	0.8	0.7	1.0	1.1
Total	39.5	46.4	50.5	61.6
Source: (FAO, 2010)				

Mustard plant belongs to the genus *Brassica* under the family Cruciferae. In our country, mainly three species are cultivated namely, *Brassica campestris, Brassica juncea* and *Brassica napus*. Of these, *B. napus* and *B. campestris* have the greatest importance in the world's oilseed trait. In this sub-continent *B. juncea* is also an important oilseed crop. Mustard varieties such as Tori-7, Sampad (Both are *B. campestris*) and Doulot (*B. juncea*) are mainly grown in this country. Recently MM-2-16-98, MM-34-7, MM-38-6-98, BINA Sarisha-4 high yielding varieties have been developed by the scientist of Bangladesh Institute of Nuclear Agriculture (BINA). Recently in 2006 Sher-e-Bangla Agricultural University has developed a high yielding and improved mustard variety (SAU Sharisha-1).

Mustard is a cold loving crop and grows during Rabi season (Oct-Feb) usually under rainfed and low input condition in this country. It is a thermo-sensitive as well as photosensitive crop (Ghosh and Chatterjee, 1998). It provides good coverage of the soil in winter, and limits nitrogen run-off. There is very little scope of expansion for mustard and other oil seed cultivation in the country due to competition with more profitable alternative crops. With increasing growth rate of population the demand of edible oil is increasing day by day. It is, therefore, highly expected that the production of edible oil should be increased considerably to fulfill the demand of the country. But the production of mustard is hampered due to many reasons such as suitable varieties, imbalanced use of fertilizer, negligible irrigation facilities and so on (Sheppard and Baten, 1980). Though the production of edible oil is being decreased in our country but demand is increasing day by day with the increasing population. The present domestic edible oilseed production is 267 thousand ton which meets only one third of national demand (Anonymous, 2006).

However, it is possible to increase the yield by adopting improved cultural practices. The use of high yielding varieties coupled with application of balanced fertilizer might be a good means to enhance mustard yield. The practice of intensive cropping with modern varieties cause a marked depletion of inherent nutrient reserves in soil of Bangladesh.

Rapeseed is currently grown with a high level of nitrogen-containing fertilizers, and the manufacture of these generates N_2O, a potent greenhouse gas with 296 times the global warming potential of CO_2. It has been estimated that 3-5% of nitrogen provided as fertilizer for rapeseed is converted to N_2O.

The decline of soil fertility is the main cause of low productivity of the cultivated lands. So far the emphasis has been given to supplement the soil with the major nutrients Viz., N, P, K, S and micronutrients (Zn, Fe, Cu, and Mn) could be met from the soil reserve. According to soil test finding use of limited recycling of plant residues and gap between the removal and supplementation of secondary and micro-nutrients have resulted in widespread multiple nutrient deficiencies, especially of N, P, K, S and Zn along with other nutrients (Fe and Cu). In recent years sulphur deficiency has been aggravated in the soil due to continuous crop-removal and use of sulphur and zinc free high analysis NPK fertilizers. Leaching and erosion losses also contribute to sulphur deficiencies (Jayalalitha and Narayanan, 1995); Saalbach (1973) reported that sulphur deficiency tends to affect adversely the growth and yield of oil seed crops, which reduce the crop yield to an extent of 10-30%. Due to the prohibitive cost of chemical fertilizer, the farmers, who are mostly marginal and small, do not apply the recommended dose of nutrients to these energy- rich crops.

Nitrogen is the most important nutrient, which determines the growth of the mustard crop and increases the amount of protein and the yield. Sulphur is also an important nutrient and plays an important role in physiological functions like synthesis of cystein, methionine, chlorophyll and oil content of oilseed crops. It is also responsible for synthesis of certain vitamins (vit-B, biotin and thiamine), metabolism of carbohydrates, proteins and oil formation of flavored compounds in crucifers. *Brassica* has the highest sulphur requirement owing to the presence of sulphur rich glucosinolates.

Indian mustard *Brassica juncea (L.)* Czern and Coss varieties under late sown condition during rabi season of 2007 and 2008 in split plot design. Results revealed that quality parameters like oil and protein content in seed and their yield were influenced significantly by various fertility levels. Oil content increased significantly with increasing fertility level upto 100% RDF (F sub(2)) and thereafter decreased with increase in fertility. However, protein content increased with increasing in fertility level and recorded the highest value at 150% RDF. Varieties recorded noticeable change in oil and protein content of mustard seed under late sown condition. (Singh *et. al.*, 2010).

Sulphur is involved in the synthesis of essential amino acids like cysteine, cystine and methionine (Kumar and Yadav, 2007). Phosphorus and potash are known to be efficiently utilized in the presence of nitrogen. It promotes flowering, setting of siliqua and in increase the size of siliqua and yield. Dembinaki *et al.* (1969) stated that phosphorus dose up to 180 kg ha^{-1} increased yield and oil content in winter rape. Singh *et al.* (1977)

reported that increase in nitrogen rate significantly increased the seed yield, where as Mudhalker and Ablawat (1981) stated that growth and yield components increased with increasing rate of N (0-80 kg ha^{-1}) and P (0-80 kg ha^{-1}), Anwar *et al.* (1992) concluded that 100-70 kg NP ha^{-1} was the optimum dose both for yield and protein contents and gave higher benefit-cost ratio (1:4). Jahan *et al.* (1992) observed that yield responded more to N and S than P and K nutrients.

Oilseed crops respond to sulphur application remarkably depending on soil type and source of its use. The functions of sulphur and phosphorus within the plant are closely related to those of nitrogen and the two nutrients are synergistic. There is a negative balance of sulphur in our soils as its addition through various sources is much lower than the removal. Phosphorus and sulphur is generally deficient in majority of our Bangladeshi soils and needs much attention for maintenance of phosphorus and sulphur in soils.

Objectives

In Bangladesh limited information is available on the effect of phosphorus and sulphur on growth, chemical composition, yield and oil content of oil producing *Brassica spp.* With the above mentioned facts in mind, the study has been undertaken with following objectives :

1. To study the individual response of phosphorus and sulphur application on growth, yield, chemical composition and oil content on SAU Sharisha-1 variety of mustard
2. To study the interaction effect of phosphorus and sulphur on growth, yield, chemical composition and oil content on SAU Sharisha-1 variety of mustard
3. To identify the suitable doses of phosphorus and sulphur for optimum growth, yield, chemical composition and oil content of mustard (SAU Sharisha-1)

CHAPTER 2
REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

It is now realized that agriculture does not only refer to crop production but also to various other factors that are responsible for crop production. Some of the published reports relevant to research topic are reviewed under the following headings:

2.1 Role of phosphorus application on mustard

Dembinaki *et. al.* (1969) stated that phosphorus dose up to 180 kg ha^{-1} increased yield and oil content in winter rape.

Bhan and Amar Singh (1976) found that the average seed yield was the highest when 40-80 kg nitrogen, 30-60 kg phosphorus and 40 kg potassium per hectare were applied.

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.

Pinkerton (1991) observed 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 factorially 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 full 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.

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

Jahan *et al.* (1992) observed that yield responded more to N and S than P and K nutrients. Ali and Rehman (1986) reported that increasing rate of N up to 160 kg ha^{-1} consistently increased the growth and yield components.

Kakai *et. 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, Tandojarn on non-saline and non-sodic medium textured soil. The NP levels comprised 0-0, 50-15, 75-30, 100-45, 125-60 and 150-75 kg NP ha^{-1}, 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, S-9 gave significantly higher seed yield but seed oil content was the highest in early Raya.

Anand (1992) studied the effect of three sub-surface drain spacings and three levels of phosphorus on the yield, chemical composition and uptake of nutrients by Indian mustard

(*Brassica juncea*). The number of siliquae m^{-2} 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 30 cm of soil.

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* L.) during 1995–97. The results showed that seed and oil yields of canola were maximized at the 90/60 kg N/P_2O_5 ha^{-1} rate of application under the agro-ecological conditions of Faisalabad, Pakistan.

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 upto 120 kg N/ha and number of seeds per siliqua upto 80 kg N ha^{-1} resulted in significant increase in seed yield upto 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. .

Bhat *et. al.* (2006) conducted a pot experiment to study the effect of three levels of nitrogen and phosphorus combinations, i.e. N_{60} P_{30} kg ha^{-1}, $N_{80}P_{40}$ kg ha^{-1} and N_{100} P_{50} kg ha^{-1}on growth, yield and quality of two cultivars of mustard (*Brassica juncea*). 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 N_{100} P_{50} kg ha^{-1} proved significantly better in improving all these parameters. Higher fertilizer dose also resulted in a significant increase in number of siliqua $plant^{-1}$, length of siliqua and number of seeds $siliqua^{-1}$, which consequently resulted in a marked increase in harvest index and seed yield of both the cultivars. N_{100} P_{50} 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.

Mir *et. al.* (2007) was conducted an experiment on mustard (*Brassica juncea* L. Czern & 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_2O_5 and K_2O 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 $plant^{-1}$ number of seed pod^{-1}, 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_2O_5

ha^{-1} and 60 kg P_2O_5 + 60 kg K_2O ha^{-1} proved optimum and the increase in seed yield was due to increase in pods $plant^{-1}$ and seeds pod^{-1}.

A field trial conducted during the winter season of 2003–2004 revealed that the growth, yield attributes and seed as well as stover yields of Indian mustard (*Brassica juncea coss*) showed linear increase in these characters upto 60 kg P/ha. Similarly, all these parameters were found to increase with increasing level of S upto 45 kg/ha and all above parameters were recorded significantly higher over control and 15 kg S/ha was non-significantly more than 30 kg S/ha (Varun, 2008).

2.2 Role of sulphur application on mustard

Clandinin (1981) reported that Canola has high requirements of Sulphur due to a combination of high protein content with high proportions of cysteine and methionine.

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).

Grand and Bailey (1993) also reported that Canola has high requirements for sulphur.

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).

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).

The poor efficiency of N caused by insufficient S needed to convert N into biomass production may increase N losses from cultivated soils (Schnug *et al.*, 1993).

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 after flowering and increases overall crop assimilation thus contributing to increased seed yield (Wright *et al.*, 1988). Sulphur (S) is increasingly being recognized as the fourth major plant nutrient after nitrogen, phosphorous and potassium (Jamal *et al.*, 2010).

Oilseed rape is particularly sensitive to sulphur deficiency. Nitrogen and sulphur are both involved in plant protein synthesis. The shortage in sulphur supply for crops decreases the N-use efficiency of fertilizers (Ceccoti, 1996).

Zhao *et. al.* (1997) found a strong interaction between N supply and the proportion of S. Sulphur is the fourth major nutrient in crop production. Most of the crops require as much sulphur as phosphorus. The nitrogen and sulphur requirements of crops are closely related because both nutrients are required for protein synthesis.

Ahmad *et. al.* (1998) conducted an experiment to assess the growth and yield of rape-seed-mustard in relation to sulphur and nitrogen interaction. Three levels of sulphur in combination with three levels of nitrogen were tested and results indicated significant favorable effects of sulphur and nitrogen, when applied together, on yield components, seed and oil yield. Maximum response was observed with treatment having S and N of 40 and 100 kg ha^{1}, respectively. Percentage oil content of seed was maximal at having S and N of 60 and 100 kg ha^{1} in both cultivars. The increase in N dose from 100 to 150 kg ha^{-1} without any change in applied S, i.e. 60 kg ha^{-1}, decreased the percentage oil content.

Among many agronomic factors responsible for low yield, imbalanced and injudicious use of fertilizers also limits the crop production. Sulphur has been reported to influence productivity of oil seed (Singh *et al.*, 1999).

Ahmad and Abdin (2000) stated that the effects of the interaction of sulphur (S) and nitrogen (N) on the oil and protein contents and the fatty acid profiles of oil in the seeds of the *Brassica* genotypes viz. *Brassica juncea* L. Czern and Coss cv. Pusa Jai Kisan (V_1) and *Brassica campestris* L. (V_2) were investigated and observations indicated that application of combined doses of S and N resulted in 5.0–10.9 % and 6.9–8.9 % enhancement in the oil content of seeds of V_1 and V_2, respectively, when compared with application of N without S . Maximum oil content (48.1 % in V_1 and 51.2 % in V_2) was observed in treatment 60 kg S ha^{-1} and 100 kg N ha^{-1}. Increases in the oleic acid and linoleic acid contents and decreases in the eicosenoic acid and erucic acid contents were recorded in both genotypes with the application of S with N, when compared with N alone. Protein, N and S contents were maximum in treatment 40 kg S ha^{-1} and 100 kg N ha^{-1}.

Ahmad *et. al.* (2000) observed the effect of sulfur (S) fertilization on oil accumulation, acetyl-CoA concentration, and activity of acetyl-CoA carboxylase (EC 6.4.1.2) in the developing seeds of rapeseed (*Brassica campestris* L. cv. Pusa Gold) grown in the field with and without S. The period between 14 and 35 days after flowering (DAF) was identified as the active period of oil accumulation in the developing seeds of rapeseed. The accumulation of oil was preceded by a marked rise in acetyl-CoA carboxylase activity and acetyl-CoA concentration, which declined rapidly when oil accumulation reached a plateau. Starch and soluble sugar content decreased, while protein content increased during the period of active oil accumulation in the developing seeds (i.e. 14–35 DAF). Sulfur fertilization significantly ($P < 0.05$) enhanced the oil accumulation in the developing seeds at all the growth stages except at 7 DAF. The increase in the oil content was 13.0–52.0% with S fertilization over the control treatment. Sulfur fertilization also increased acetyl-CoA concentration, acetyl-CoA carboxylase activity, and soluble protein, sugar, and starch content in the developing seeds. It is suggested that the increase in the oil content with S fertilization may be associated with increases in acetyl-CoA carboxylase activity through the enhancement of acetyl-CoA concentration. Further, the increased sugar content due to S fertilization provided enough carbon sources for oil biosynthesis.

Ahmad and Abdin (2000) investigated the changes in the contents of lipid, RNA and fatty acids in the developing seeds of rapeseed (*Brassica campestris* L. cv. Pusa Gold) grown with or without sulphur. Results showed that there was a positive strong co-relation between S and lipid content in the seeds. The fatty acid composition of the oil changed substantially during seed development. S application in three portions increased the oleic acid (18:1) content, and decreased the erucic acid (22:1) content over other treatments. This leads to a reduced 22:1/18:1 ratio and thus, improves the quality of oil. The ratio of erucic acid to oleic acid (22:1/18:1) is closely related to the N:S ratio in the seeds.

Singh *et. al.* (2000) reported that application of sulphur up to 45 kg ha^{-1} significantly increased the seed yield.

Jat *et. al.* (2003) concluded that application of 90 kg S ha^{-1} resulted in significantly higher seed and stalk yield.

Sulphur is involved in the synthesis of essential amino acids like cysteine, cystine and methionine (Kumar and Yadav, 2007).

Fayyaz-Ul-Hassan (2007) conducted a two year study (2003 - 04 & 2004 - 05) to document the effects of sulphur application on seed yield, oil, protein and glucosinolates contants of canola cultivars. Two canola cultivars and four sulphur levels were arranged in randomized complete design with split plot arrangement. Cultivars exhibited statistically significant variations for protein but non-significant differences for seed yield, oil and glucosinolates. Similarly, sulphur effects on seed yield, oil, protein and glucosinolates were neither significant nor consistent. However, interactive effects were observed to be significant. Seed yield, protein and glucosinolates increased during second year as compared to those observed during first year, whereas oil content exhibited an opposite trend and decreased during second year as compared to first year. Inverse relationship was observed between oil and protein during both the years of experiments.

Intensive agriculture with use of improved cultivars and high analysis fertilizers may cause conditions of nutrient exhaustion, resulting in nutrient imbalance in soils (Scherer, 2009). When a soil is deficient in S and the deficiency is not rectified, then the full potential of a crop variety cannot be realized, regardless of top husbandry practices. Canola has a high demand of S, with approximately 16 kg of S required to produce 1 ton of seeds containing 91% of dry matter (Zhao *et al.*, 1993; McGrath *et al.*, 1996).

2.3 Interaction effect of phosphorus and sulphur on mustard

A synergistic relationship between P and S was observed in Sunflower at relatively higher level of P application in the Terai area of Uttar Pradesh. With 20 kg S ha^{-1}, the relationship was additive at incraseing rates of P but with 40 kg S ha^{-1} seed weight went up markedly at 60 kg P_2O_5 ha^{-1} (Gangwar and Parameswaran, 1976).

In rapeseed mustard, a+ve interaction between P and S was reported in pot culture and field trial (Rauth and Ali, 1986). S increase seed yield by 41%, P incrased it by 49% and remaining 10% was attribute to their synergistic effect (Rauth and Ali, 1986).

In experiments on black clay soil of Jabalpur, Madhya Pradesh analyzing 12.5kgavailable P_2O_5 ha^{-1} and 14.4kg available S ha^{-1}, both the nutrient to exert a strongsynergistic relationship for fababean nutrition (Nayak and Dwivedi, 1990).

In soybeans the interaction between P and S was synergistic at 35kg P (Aulakh *et al.* 1990).

Both positive and negative interactions have been reported but recent research has shown that the nature of P-S interaction depends on their rate of application. Several workers have reported that the P×S interaction is synergistic at low to medium levels of P and atagonstic only at higher levels, usually at 60 or more Kg P_2O_5 ha^{-1} for field crops. (Ali 1991, Aulakh *et al.*, 1989, 1990, Pasricha *et al.* 1987).

An experiment with pigeonpea at Kanke, Bihar also showed the P×S interaction to be rated depended. It was absent at 20-40kg P_2O_5 with 20 kg S ha^{-1} strongly synergistic at 40-60 kg P_2O_5 with 20-40 kg S and tended towards being antagonistic under 60kg P_2O_5 +40kg S ha^{-1}. Highest total response (+1150 kg grain ha^{-1}) highest synergistic benefit (35%) was obtained from 60 kg P_2O_5 +20kg S ha^{-1}.(Ali 1991).

Ram Baldev and Pareek (2000) conducted an experiment on loamy sand soil of Jobner (Rajasthan) to find out the effect of phosphorus, sulphur on yield, oil content and nutrient uptake by mustard. Application of 30 kg P_2O_5 ha^{-1} 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 significant over control only. Application of 90 kg S ha^{-1} being at par with S_{60} 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 investigations on *Brassica juncea* cv. RH-30 under screen house conditions with salinity levels of 0, 8 and 12 dsm^{-1} and with the use of phosphorus (20, 40, 60 kg ha^{-1}) and Sulphur (10, 20 and 30 kg ha^{-1}) and their combinations (20 kg P ha^{-1} + 10 kg S ha^{-1}, 40 kg P ha^{-1} + 20 kg S ha^{-1} and 60 kg P ha^{1} + 30 kg S ha^{-1}) after emergence of seedlings. Under saline irrigation, different growth 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^{-1} + 30 kg S ha^{-1}) exhibited maximum alleviation (ranging from 24 to 46 percent) of the adverse effect of salinity.

CHAPTER 3
MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

This chapter includes a brief description 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, yield and oil content of mustard.

3.1 Experimental site

The research work relating to the study of the role of P and S on the growth, yield and oil content of mustard was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka 1207 during the *Rabi* season of 2010-2011. The following map shows the specific location of experimental site (Figure 1).The experimental site was located at $23^0 77$ N latitude and $90^0 3$ E longitudes with an elevation of 1.0 meter from sea level.

3.2 Climate

The annual precipitation of the site is 2152 mm and potential evapotranspiration is 1297 mm. The average maximum temperature is 30.34 ^{0}C and average minimum temperature is 21.21^{0}C. The average mean temperature is 25.17 ^{0}C. The experiment was done during the *rabi* season. Temperature during the cropping period was ranged between 12.20 ^{0}C to 29.2 ^{0}C. The humidity varies from 73.52 % to 81.2 5%. The day length was reduced to 10.5 – 11.0 hours only and there was a very little rainfall from the beginning of the experiment to harvesting.

3.3 Description of soil

The soil of the experimental field belongs to the Tejgaon series under the Agro ecological Zone, Madhupur Tract (AEZ- 28) and the General soil type is Deep Red Brown Terrace Soils. A composite sample was made by collecting soil from several spots of the field at a depth of 0-15 cm before the initiation of the experiment. The collected soil was air-dried, ground and passed through 2 mm sieve and analyzed for some important physical and chemical parameters. The morphological characteristics of the experimental field and initial physical and chemical characteristics of the soil are presented in Table 3.1 and Table 3.2.

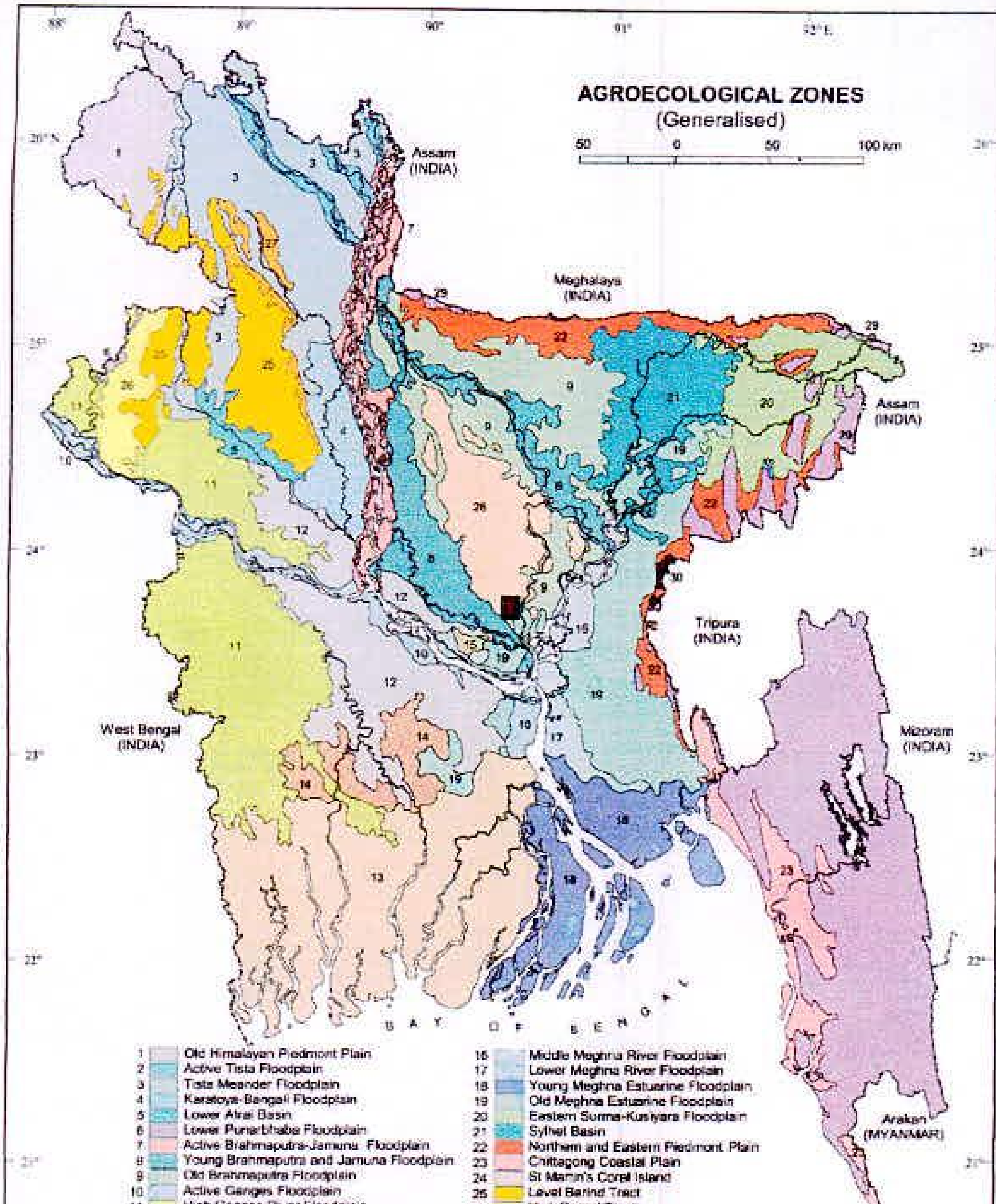

Fig.1. Map showing the experimental site under study

Table 3.1 Morphological characteristics of experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Farm, Dhaka
AEZ No. and 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

Table 3.2 Initial characteristics of soil of the experimental field

1. Particle-size analysis of soil	Sand (%)	30.55
	Silt (%)	37.29
	Clay (%)	32.16
2. Textural Class		Clay loam
3. p^H		5.8
4. Total N (%)		0.082
5. Organic matter (%)		1.05
6. Available phosphorous (mg kg^{-1})		12
7. Available potassium (cmol/ kg)		0.146
8. Available sulphur (mg kg^{-1})		14

Plot size: 2.5m x 2.0m
Plot to plot distance: 0.5m
Block to block distance: 1m

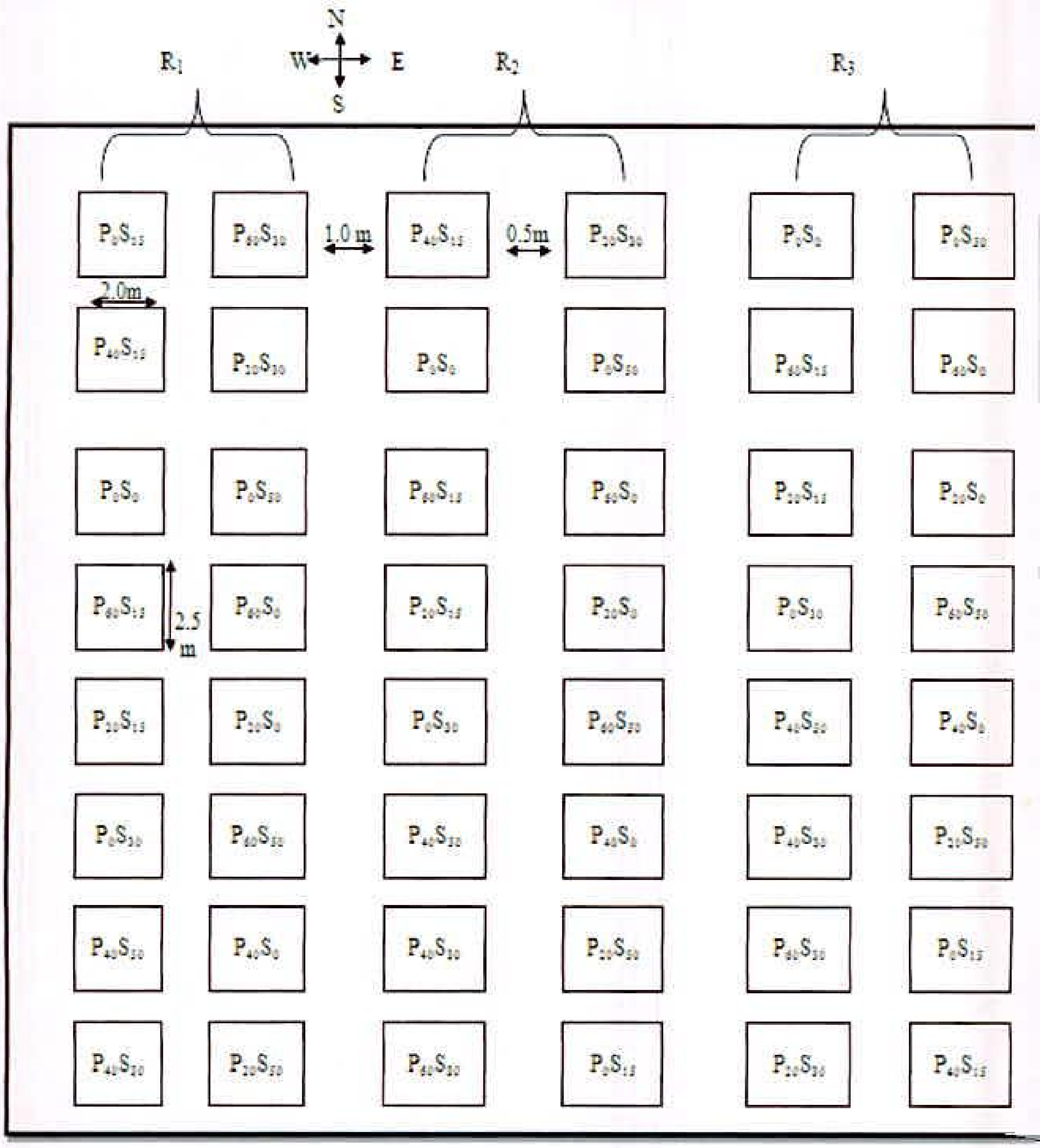

Fig.2. Layout of the experimental field

3.4 Description of the mustard variety

SAU Sharisha-1, a high yielding and short duration variety of mustard was used as the test crop in this experiment. This variety was developed by Sher-e-Bangla Agricultural University (SAU), Dhaka. The seeds were collected from Genetics and Plant Breeding Department of SAU, Dhaka.

3.5 Preparation of the field

The plot selected for the experiment was opened by power tiller driven rotovator on the 25^{th} October 2010; afterwards the land was ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed, and the large clods were broken into smaller pieces to obtain a desirable tilth of soil for sowing of seeds. Finally, the land was leveled and the experimental plot was partitioned into the unit plots in accordance with the experimental design mentioned in the following section (3.6).

3.6 Layout of the experiment

The experiment was laid out in a Randomized Complete Block Design with three replications. The total numbers of plots were 48, each measuring 2.5 m x 2.0 m ($5m^2$). The treatment combination of the experiment was assigned at random into 16 plots of each at 3 replications. The adjacent block and neighboring plots were separated by 1.0 m and 0.5 m, respectively. The layout of the experiment is presented in Figure 2.

3.7 Treatments

Fertilizer treatments consisted of 4 levels of P (0, 20, 40 and 60 kg P ha^{-1} designated as P_0, P_{20}, P_{40} and P_{60}, respectively) and 4 levels of S (0, 15, 30 and 50 kg S ha^{-1} designated as S_0, S_{15}, S_{30} and S_{50}, respectively).There were 16 treatment combinations. The rates of P and S and their treatment combinations are shown below:

A. Rates of phosphorus (4):

- P_0 = 0 kg P ha^{-1}
- P_{20} = 20 kg P ha^{-1}
- P_{40} = 40 kg P ha^{-1}
- P_{60} = 60 kg P ha^{-1}

B. Rates of sulphur (4):

1. S_0 = 0 kg S ha^{-1}
2. S_{15} = 15 kg S ha^{-1}
3. S_{30} = 30 kg S ha^{-1}
4. S_{50} = 50 kg S ha^{-1}

C. Treatment combinations

- P_0 S_0= Control (Without P and S)
- $P_{20}S_0$= 20 kg P ha^{-1} + 0 kg S ha^{-1}
- $P_{40}S_0$= 40 kg P ha^{-1} + 0 kg S ha^{-1}
- $P_{60}S_0$= 60 kg P ha^{-1} + 0 kg S ha^{-1}
- P_0S_{15}= 0 kg P ha^{-1} + 15 kg S ha^{-1}
- $P_{20}S_{15}$= 20 kg P ha^{-1} + 15 kg S ha^{-1}

- $P_{40}S_{15}$= 40 kg P ha^{-1} + 15 kg S ha^{-1}
- $P_{60}S_{15}$= 60 kg P ha^{-1} + 15 kg S ha^{-1}
- P_0S_{30}= 0 kg P ha^{-1} + 30 kg S ha^{-1}
- $P_{20}S_{30}$= 20 kg P ha^{-1} + 30 kg S ha^{-1}
- $P_{40}S_{30}$= 40 kg P ha^{-1} + 30 kg S ha^{-1}
- $P_{60}S_{30}$ = 60 kg P ha^{-1} + 30 kg S ha^{-1}
- P_0S_{50}= 0 kg P ha^{-1} + 50 kg S ha^{-1}
- $P_{20}S_{50}$= 20 kg P ha^{-1} + 50 kg S ha^{-1}
- $P_{40}S_{50}$= 40 kg P ha^{-1} + 50 kg S ha^{-1}
- $P_{60}S_{50}$= 60 kg P ha^{-1} + 50 kg S ha^{-1}

3.8 Application of fertilizers

Recommended doses of N, K, Zn and B (120 kg N from urea, 40 kg K from MOP, 2 kg Zn from ZnO and 1 kg B ha^{-1} from Boric acid) were applied as basal dose at November 5, 2010.

The whole 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 28 days of germination on December 3, 2010. The required amounts of P (from TSP) and S were applied at a time as per treatment combination after land preparation were mixed properly through hand spading.

3.9 Seed sowing

Mustard seeds were sown on the 5th November 2010 in lines following the recommended line to line distance of 30 cm and plant to plant distance of 5 cm.

3.10 Weeding and thinning

Weeds of different types were controlled manually and removed from the field. The weeding and thinning were done after 30 days of sowing, on December 6, 2010. Second weeding was done on December 20, 2010. Care was taken to maintain constant plant population per plot.

3.11 Irrigation

Irrigation was given at three times. The first irrigation was given in the field on November 15, 2010 at ten days after sowing (DAS) through irrigation channel. Second irrigation was given in the field on December 15, 2010 at 40 days after sowing (DAS) before flowering. The third irrigation was given at the stage of pod formation (70 DAS) on January 01, 2011.

3.12 Pest management

The crop was infested with cutworm at the seedling stage and application of Dursban-25EC @ 2.5ml/liter was done twice on January 12 and 20, 2011. 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. The insecticide was sprayed thrice, the first December 20, 2010, the second January 5, 2011 and the last on

January 25, 2011. Special care was taken to protect the crop from birds especially after sowing and germination stages.

3.13 Harvesting and threshing

The crop was harvested at maturity on 19th February 2011. The harvested crop of each individual plot was bundled separately and carried to the threshing floor. The plants were sun dried by spreading the bundles on the threshing floor. The seeds were separated from the stover by beating the bundles with bamboo sticks.Seed yield and stover yield were recorded plot wise and the yields were expressed in t ha^{-1}.

3.14 Collection of samples

3.14.1 Soil Sample

The initial soil sample was collected randomly from different spots of the field selected for the experiment at 0-15 cm depth before the land preparation and mixed thoroughly to make a composite sample for analysis. Post harvest soil samples were collected from each plot at 0-15 cm depth on 24th February 2011. The samples were air-dried, ground and sieved through a 2 mm (10 meshes) sieve and kept for analysis.

3.14.2 Plant sample

Plant samples were collected from every individual plot for laboratory analysis at the harvesting stage of the crop. Ten plants were randomly collected from each plot by cutting above the ground level. The plant samples were washed first with tape water and then with distilled water for several times. The plant samples were dried in the electric oven at 70^0 C for 48 hours. After that the samples were ground in an electric grinding machine and stored for chemical analysis. The plant samples were collected by avoiding the border area of the plots.

3.15 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 (ton/ha)
- Oil content in seed
- Protein content in seed
- N, P, K and S contents in plant sample
- N, P, K, S, organic carbon contents in post harvest soil

3.15.1 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.

3.15.2 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.

3.15.3 Number of siliqua /plant

Siliqua were counted at the ripening stage and 10 plants were selected from each plot and averaged.

3.15.4 Length of siliqua

Length of 10 siliqua from each plot were measured randomly after harvest and averaged.

3.15.5 Number of seeds / siliqua

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

3.15.6 Weight of thousand seeds

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

3.15.7 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}.

3.15.8 Stover yield

Stover remained after collection of seeds (1 m^2 of each individual plot) were dried, weighed carefully and the yield was expressed in t ha^{-1}.

3.16 Chemical analysis of the soil and seed samples

3.16.1 Plant sample analysis

The plant samples collected after harvesting of the crop were digested with conc. HNO_3 and $HClO_4$ mixture for the determination of P, K and S.

3.16.1. a) Nitrogen

Plant samples were digested with conc. $HClO_3$, conc. H_2SO_4 and a catalyst mixture (K_2SO_4 : $CuSO_4.5H_2O$: Selenium powder in the ratio 100 : 10 : 1, respectively) for the determination of total nitrogen by Micro-Kjeldahl method. Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate absorbed in H_3BO_3 with 0.01N H_2SO_4 (Jackson, 1973).

3.16.1. b) Phosphorous

Phosphorous in the digest was determined by ascorbic acid blue color method (Murphy and Riley, 1962) with the help of a Spectrophotometer (LKB Novaspec, 4049).

3.16.1. c) Potassium

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

3.16.1. d) Sulphur

Sulphur content in the digest was determined by turbidimetric method as described by Hunt (1980) using a Spectrophotometer (LKB Novaspec, 4049).

3.16.2 Soil sample analysis

3.16.2. a) Organic carbon

Soil organic carbon was determined by Walkley and Black's wet oxidation method as outlined by Jackson (1973) from the samples collected before sowing and also after harvesting the crop.

3.16.2. b) Organic matter

The organic matter content was determined by multiplying the percent organic carbon with Van Bemmelen factor 1.73 (Piper, 1950).

3.16.2. c) Total nitrogen

Total nitrogen of soil samples were estimated by Micro-Kjeldahl method where soils were digested with conc HNO_3, conc. $HClO_3$ and catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Selenium powder in the ratio 100 :10 :1, respectively). Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate absorbed in H_3BO_3 with 0.01N H_2SO_4 (Jackson, 1973).

3.16.2. d) Available Phosphorous

Available phosphorous was extracted from the soil by Bray-1 method (Bray and Kurtz, 1945). Phosphorous in the extract was determined by ascorbic acid blue color method (Murphy and Riley, 1962) with the help of a Spectrophotometer (LKB Novaspec, 1949).

3.16.2. e) Available Potassium

Available potassium in the soil sample was extracted with 1N neutral ammonium acetate and the potassium content was determined by flame photometer.

3.16.2. f) Available Sulphur

Available sulphur was extracted from the soil with $Ca(H_2PO_4)_2.H_2O$ (Fox *et al.*, 1964). Sulphur in the extract was determined by the turbidimetric method as described by Hunt (1980) using a Spectrophotometer (LKB Novaspec, 4049).

3.16.2. g) Soil pH

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

3.17 Methods for seed analysis

3.17.1 Protein content in seed (%): Protein content in seed was estimated by multiplying N (%) in seed with 6.25.

Total protein (%) = Total N (%) x 6.25.

3.17.2 Oil content in seed (%): Oil content of mustard seed was estimated by Swedish Soxhlet method. (As described by South Combe, 1926).

3.18 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 4
RESULTS AND DISCUSSION

Chapter 4

RESULTS AND DISCUSSION

The results on different yield attributes, yield, oil content and nutrient concentrations in the plants and availability of different nutrients in the soil after harvest of mustard are presented in this chapter.

4.1 Growth parameter

4.1.1 Effect of phosphorus on the plant height of mustard

The effects of phosphorus on the plant height of mustard are presented in Table 4.1. Insignificant variation was observed on the plant height of mustard when the field was fertilized with different doses of phosphorus. Among the different doses of phosphorus, P_{60} (60 kg P ha^{-1}) showed the highest plant height (110.1 cm). On the other hand, the lowest plant height (105.2 cm) was observed in the P_0 treatment where no phosphorus was applied. 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.

Table 4.1 Effect of P on the growth parameters of mustard

Treatments	Plant height (cm)	Number of primary branches plant^{-1}	Number of siliqua plant^{-1}	Siliqua length (cm)
P_0	105.2	5.450	82.37	6.455
P_{20}	106.9	5.500	75.58	6.664
P_{40}	109.5	5.317	91.75	6.616
P_{60}	110.1	5.767	91.45	6.662
$LSD_{0.05}$	**NS**	**NS**	**NS**	**NS**
CV (%)	**6.68**	**19.31**	**33.06**	**3.32**

4.1.2 Effect of sulphur on the plant height of mustard

Mustard plants showed insignificant variation in respect of plant height when sulphur fertilizer in different doses was applied (Table 4.2). Among the different fertilizer doses, S_{50} (50 kg S ha^{-1}) showed the highest plant height (110.2 cm). On the contrary, the lowest plant height (104.7 cm) was observed in the treatment S_0 where no sulphur fertilizer was applied. Plant height increased with increasing levels of sulphur. The increased plant height may be due to favorable effects of sulphur on the vegetative growth of mustard plant.

Table 4.2 Effect of S on the growth parameters of mustard

Treatments	Plant height (cm)	Number of primary branches $plant^{-1}$	Number of siliqua $plant^{-1}$	Siliqua length (cm)
S_0	104.7	5.683	81.23	6.535
S_{15}	108.4	5.733	94.65	6.678
S_{30}	108.3	5.367	83.02	6.592
S_{50}	110.2	5.250	82.25	6.592
$LSD_{0.05}$	**NS**	**NS**	**NS**	**NS**
CV	**6.68**	**19.31**	**33.06**	**3.32**

4.1.3 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 4.3).The lowest plant height (100 cm) was observed in the control treatment (no phosphorus and no sulphur). On the other hand, the highest plant height (116.7 cm) was recorded with $P_{60}S_{50}$ (60 kg P ha^{-1} + 50 kg S ha^{-1}) which was statistically similar with the $P_{40}S_{50}$ (40 kg P ha^{-1} + 50 kg S ha^{-1}) treatment. The highest plant height may be due to the positive effects of phosphorus and sulphur on the vegetative growth of the plant.

Table 4.3 Interaction effect of P and S on the growth parameters of mustard

Treatments	Plant height (cm)	Number of primary branches plant^{-1}	Number of siliqua plant^{-1}	Siliqua length (cm)
P_0S_0	100.0 b	5.933	80.60 cde	6.277 b
P_0S_{15}	105.8 ab	5.533	91.80 bc	6.715 a
P_0S_{30}	112.3 ab	4.867	81.60 bcde	6.427 ab
P_0S_{50}	102.7 ab	5.467	75.47 cde	6.403 ab
$P_{20}S_0$	103.8 ab	5.333	72.87 de	6.633 ab
$P_{20}S_{15}$	112.5 ab	5.467	80.07 cde	6.683 ab
$P_{20}S_{30}$	104.8 ab	6.133	79.47 cde	6.600 ab
$P_{20}S_{50}$	106.3 ab	5.067	69.93 e	6.740 a
$P_{40}S_0$	107.3 ab	5.267	85.67 bcde	6.647 ab
$P_{40}S_{15}$	107.4 ab	5.933	108.7 a	6.677 ab
$P_{40}S_{30}$	108.1 ab	5.200	81.33 bcde	6.593 ab
$P_{40}S_{50}$	115.1 a	4.867	91.27 bc	6.547 ab
$P_{60}S_0$	107.8 ab	6.200	85.80 bcde	6.583 ab
$P_{60}S_{15}$	107.7 ab	6.000	98.00 ab	6.637 ab
$P_{60}S_{30}$	108.0 ab	5.267	89.67 bcd	6.747 a
$P_{60}S_{50}$	116.7 a	5.600	92.33 bc	6.680 ab
$LSD_{0.05}$	**12.03**	**1.774**	**14.89**	**0.3653**
CV (%)	**6.68**	**19.31**	**33.38**	**9.69**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

4.2 Number of primary branches plant^{-1}

4.2.1 Effect of phosphorus on the number of primary 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 (Table 4.1). The highest number of primary branches plant^{-1} (5.767) was recorded in P_{60} (60 kg P ha^{-1}). The lowest number of primary branches plant^{-1} (5.317) was recorded in the P_{40} (40 kg P ha^{-1}) treatment.

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

Different doses of sulphur fertilizer showed insignificant variations in respect of number of primary branches plant^{-1} (Table 4.2). Among the different doses of sulphur, S_{15} (0 kg S ha^{-1}) showed the highest number of primary branches plant^{-1} (5.733). On the contrary, the lowest number of primary branches plant^{-1} (5.250) was recorded in the S_{50} treatment. The decrease number of primary 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.

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

The combined effect of different doses of P and S fertilizers on the number of primary branches plant^{-1} of mustard was insignificant (Table 4.3). The highest number of primary branches plant^{-1} (6.2) was recorded with the treatment combination of $P_{60}S_0$ (60 kg P ha^{-1}

+ 0 kg S ha^{-1}). On the other hand, the lowest number of primary branches $plant^{-1}$ (4.87) was recorded in the P_0S_{30} and $P_{40}S_{50}$ treatments.

4.3 Number of siliqua $plant^{-1}$

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

Insignificant variation was observed in the number of siliqua $plant^{-1}$ of mustard when different doses of phosphorus were applied (Table 4.1). The highest number of siliqua $plant^{-1}$ (91.75) was recorded in P_{40} (40 kg P ha^{-1}) treatment. The lowest number of pod $plant^{-1}$ (75.58) was recorded in the P_{20} treatment.

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

Different doses of sulphur fertilizer showed insignificant variations in respect of number of siliqua $plant^{-1}$ (Table 4.2). Among the different doses of fertilizers, S_{15} (15 kg S ha^{-1}) showed the highest number of siliqua $plant^{-1}$ (94.65). On the contrary, the lowest number of siliqua $plant^{-1}$ (81.23) was recorded in the S_0 treatment where no sulphur fertilizer was applied. Higher doses of S (S_{30} and S_{50}) showed decreased number of siliqua per plant which may be due to the negative effect of higher S doses on the growth of mustard.

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

The combined effect of different doses of P and S fertilizers on the number of siliqua $plant^{-1}$ of mustard was significant (Table 4.3). The highest number of siliqua $plant^{-1}$ (108.7) was recorded with the treatment combination of $P_{40}S_{15}$ (40 kg P ha^{-1} + 15 kg S ha^{-1}) which was statistically similar with $P_{60}S_{15}$ (60 kg P ha^{-1} + 15 kg S ha^{-1}) treatment. On the other hand, the lowest number of siliqua plant^{-1} (69.93) was recorded in the $P_{20}S_{50}$ treatment. The highest number of siliqua plant^{-1} 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.

4.4 Length of siliqua plant^{-1}

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

Insignificant variation was observed on the length of siliqua plant^{-1} of mustard when different doses of phosphorus were applied (Table 4.1). Almost similar lengths of siliqua were observed in all the treatments of P.

4.4.2 Effect of sulphur on the length of siliqua plant^{-1} of mustard

Different doses of sulphur fertilizer showed insignificant variations in respect of length of siliqua plant^{-1} (Table 4.2). Among the different doses of fertilizers, S_{15} (15 kg S ha^{-1}) showed the highest length of siliqua plant^{-1} (6.678). The length of siliqua were almost similar in other treatments of S.

4.4.3 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 number of siliqua plant^{-1} of mustard was significant (Table 4.3). The highest length of siliqua plant^{-1} (6.74) was recorded with the treatment combinations of $P_{60}S_{30}$ and $P_{20}S_{50}$. Siliqua length were recorded almost same in the remaining P and S treatment combinations except P_0S_0 treatment which showed the lowest siliqua length.

4.5 Number of seed siliqua^{-1}

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

Insignificant variation was observed in the number of seed siliqua^{-1}of mustard when different doses of phosphorus were applied (Table 4.4). The highest number of seed siliqua^{-1} (21.73) was recorded in P_0 (0 kg P ha^{-1}) treatment. The lowest number of seed siliqua^{-1} (20.47) was recorded in the P_{20} treatment. The number of seed siliqua^{-1} did not increase with increasing levels of phosphorus up to certain level.

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

Different doses of sulphur fertilizer showed insignificant variations in respect of number of seed siliqua^{-1} (Table 4.5). Among the different doses of fertilizers, S_{50} (50 kg S ha^{-1}) showed the highest number of seed siliqua^{-1} (22.09). On the contrary, the lowest number of seed siliqua^{-1} (19.93) was recorded in the S_{30} treatment.

4.5.3 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 4.6). The highest number of seeds plant^{-1}

(23.11) was recorded with the treatment combination of P_0S_{50} (0 kg P ha^{-1} + 50 kg S ha^{-1}) which were statistically similar with all other treatment combinations.

4.6 Weight of 1000 seed (g)

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

Insignificant variation was observed on the weight of 1000 seed of mustard when different doses of phosphorus were applied (Table 4.4). The highest weight of 1000 seed (3.003g) was recorded in P_{60} (60 kg P ha^{-1}) treatment. The lowest weight of 1000 seed (2.828 g) was recorded in the P_{20} 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.

4.6.2 Effect of sulphur on the weight of 1000 seed of mustard

Different doses of sulphur fertilizer showed insignificant variations in respect of the weight of 1000 seed (Table 4.5). Among the different doses of S fertilizer, S_{30} (30 kg S ha^{-1}) showed the highest weight of 1000 seed (3.020 g). On the contrary, the lowest weight of 1000 seed (2.832g) was recorded in the S_{50} treatment. This may be due to negative effect of highest S dose (S_{50}) on the grain weight of mustard.

Table 4.4 Effect of P on the yield parameters of mustard

Treatments	Number of seed siliqua^{-1}	Weight of 1000 seeds (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})
P_0	21.73	2.914	1.960	6.655
P_{20}	20.47	2.828	1.950	6.547
P_{40}	21.44	2.900	2.370	8.688
P_{60}	21.34	3.003	2.447	5.960
$LSD_{0.05}$	**NS**	**NS**	**NS**	**NS**
CV (%)	**6.69**	**9.87**	**4.14**	**52.32**

4.6.3 Interaction effect of phosphorus and sulphur on the weight of 1000 seed of mustard

The combined effect of different doses of P and S fertilizers on the weight of 1000 seed of mustard was significant (Table 4.6). The highest weight of 1000 seed (3.23 g) was recorded with the treatment combination of $P_{60}S_0$ (60 kg P ha^{-1} + 0 kg S ha^{-1}) which was statistically similar with all other treatment combinations.

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

4.7.1 Effect of phosphorus on the seed yield of mustard

Insignificant variation was observed on the seed yield of mustard when different doses of phosphorus were applied (Table 4.4). The highest seed yield of mustard (2.447 t ha^{-1}) was recorded in P_{60} (60 kg P ha^{-1}) treatment. The lowest seed yield (1.950 t ha^{-1}) was recorded in the P_{20} treatment. The increased seed yield may be due to the positive effects of phosphorus on the vegetative growth that helped proper growth and development of the mustard seed.

4.7.2 Effect of sulphur on the seed yield of mustard

Different doses of sulphur fertilizer showed insignificant variations in respect of seed yield of mustard (Table 4.5). Among the different doses of S fertilizer, S_{30} (30 kg S ha^{-1}) showed the highest seed yield of mustard (2.345 t ha^{-1}) treatment. On the contrary, the lowest weight seed yield of mustard (1.908 t ha^{-1}) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased seed yield may be due to the favourable effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the mustard seed.

Table 4.5 Effect of S on the yield parameters of mustard

Treatment	Number of seed $siliqua^{-1}$	Weight of 1000 seeds (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})
S_0	21.81	2.841	1.908	6.577
S_{15}	21.16	2.952	2.250	5.830
S_{30}	19.93	3.020	2.345	7.185
S_{50}	22.09	2.832	2.223	8.258
$LSD_{0.05}$	**NS**	**NS**	**NS**	**NS**
CV (%)	**6.69**	**9.87**	**4.14**	**52.32**

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

The combined effect of different doses of P and S fertilizers on the seed yield of mustard was significant (Table 4.6). The highest seed yield of mustard (2.86 t ha^{-1}) was recorded with the treatment combination of $P_{60}S_{15}$ (60 kg P ha^{-1} + 15 kg S ha^{-1}). On the other hand, the lowest seed yield of mustard (1.61 t ha^{-1}) was recorded in the $P_{20}S_0$ treatment.

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

4.8.1 Effect of phosphorus on the stover yield of mustard

Insignificant variation was observed on the stover yield of mustard when different doses of phosphorus were applied (Table 4.4). The highest stover yield of mustard (8.688 t ha^{-1}) was recorded in P_{40} (40 kg P ha^{-1}) treatment. The lowest stover yield (5.960 t ha^{-1}) was recorded in the P_{60} treatment. This may be due to the suppressive effect of high dose of P.

4.8.2 Effect of sulphur on the stover yield of mustard

Different doses of sulphur fertilizer showed insignificant variations in respect of stover yield of mustard (Table 4.5). Among the different doses of S fertilizer, S_{50} (50 kg S ha^{-1}) showed the highest stover yield of mustard (8.258 t ha^{-1}). On the contrary, the lowest stover yield of mustard (5.830 t ha^{-1}) was recorded in the S_{15} treatment.

4.8.3 Interaction effect of phosphorus and sulphur fertilizers on the stover yield

The combined effect of different doses of P and S fertilizers on the stover yield of mustard was insignificant (Table 4.6). The highest sttover yield of mustard (10.07 t ha^{-1}) was recorded with the treatment combination of $P_{40}S_0$ (40 kg P ha^{-1} + 0 kg S ha^{-1}). On the other hand, the lowest stover yield of mustard (4.353 t ha^{-1}) was recorded in the $P_{60}S_{15}$ treatment.

Table 4.6 Interaction effect of P and S on the yield parameters of mustard

Treatments	Number of seed siliqua^{-1}	Weight of 1000 seeds (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})
P_0S_0	21.76 a	3.010 a	1.657 gh	6.633
P_0S_{15}	21.83 a	2.923 a	2.20 d	5.30
P_0S_{30}	20.23 ab	2.900 a	1.96 f	5.02
P_0S_{50}	23.11 a	2.823 ab	2.023 ef	9.667
$P_{20}S_0$	21.23 a	2.310 b	1.61 h	4.62
$P_{20}S_{15}$	21.33 a	2.807 ab	1.77 g	5.20
$P_{20}S_{30}$	17.32 b	3.170 a	1.95 f	8.567
$P_{20}S_{50}$	22.01 a	3.027 a	2.47 c	7.80
$P_{40}S_0$	22.66 a	2.810 ab	2.44 c	10.07
$P_{40}S_{15}$	21.28 a	3.167 a	2.17 de	8.467
$P_{40}S_{30}$	20.77 ab	2.867 a	2.70 b	8.787
$P_{40}S_{50}$	21.07 ab	2.757 ab	2.17 de	7.433
$P_{60}S_0$	21.58 a	3.233 a	1.927 f	4.987
$P_{60}S_{15}$	20.21 ab	2.910 a	2.86 a	4.353
$P_{60}S_{30}$	21.40 a	3.143 a	2.77 ab	6.367
$P_{60}S_{50}$	22.16 a	2.723 ab	2.23 d	8.133
$LSD_{0.05}$	**3.434**	**0.4804**	**0.1491**	**NS**
CV (%)	**3.32**	**9.87**	**4.17**	**52.248**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

4.9 Total nitrogen content in mustard plant

4.9.1 Effect of P on nitrogen content in mustard plant

Application of P showed insignificant variation on the nitrogen concentration in mustard plant (Table 4.7). The highest nitrogen concentration in mustard plant (0.1311%) was recorded in P_{40} (40 kg P ha^{-1}) treatment. On the other hand, the lowest nitrogen concentration in mustard plant (0.1195%) was recorded in the P_{60} treatment.

4.9.2 Effect of S on nitrogen content in mustard plant

A statistically insignificant variation was observed on phosphorus concentration in mustard plant with different doses of sulphur (Table 4.8). However, the highest phosphorus concentration (0.1399 %) among the different doses of sulphur was recorded in P_{30} (30 kg S ha^{-1}). On the other hand, the lowest phosphorus concentration in mustard plant (0.1116 %) was recorded in the S_{15}.

4.9.3 Interaction effect of P and S on nitrogen content in mustard plant

Significant effect of combined application of different doses of P and S fertilizers on the nitrogen concentration was observed in the mustard plant (Table 4.9). The highest concentration (0.1603%) of nitrogen in the mustard plant was recorded with $P_{20}S_{30}$ (20 kg P ha^{-1} + 30 kg S ha^{-1}) treatment. On the other hand, the lowest nitrogen concentration in mustard plant (0.1020%) was observed in the $P_{20}S_{15}$ treatment.

4.10 Total phosphorus content in mustard plant

4.10.1 Effect of P on phosphorus content in mustard plant

A statistically insignificant variation was observed on phosphorus concentration in mustard plant with different doses of phosphorus (Table 4.7). However, the highest phosphorus concentration (4.724%) among the different doses of phosphorus was recorded in P_{60} (60 kg P ha^{-1}). On the other hand, the lowest phosphorus concentration in mustard plant (3.68%) was recorded in the P_0 treatment where no P was applied.

Table 4.7 Effect of P on the N, P, K and S contents in mustard plant

Treatments	Total Nitrogen (%)	Total Phosphorus (%)	Total Potassium (%)	Total Sulfur (%)
P_0	0.1249	3.680	0.4859	0.1877
P_{20}	0.1294	4.097	0.5027	0.1682
P_{40}	0.1311	4.253	0.5162	0.1610
P_{60}	0.1195	4.724	0.5154	0.1810
$LSD_{0.01}$	**NS**	**NS**	**NS**	**NS**
CV (%)	**3.96**	**1.28**	**0.89**	**3.06**

4.10.2 Effect of S on phosphorus content in mustard plant

A statistically insignificant variation was observed on phosphorus concentration in mustard plant with different doses of sulphur (Table 4.8). However, the highest phosphorus concentration (0.4296 %) among the different doses of sulphur was recorded in S_{15} (15 kg S ha^{-1}). On the other hand, the lowest phosphorus concentration in mustard plant (0.4112 %) was recorded in the S_0 treatment where no S was applied.

4.10.3 Interaction effect of P and S on phosphorus content in mustard plant

Significant effect of combined application of different doses of P and S fertilizers on the phosphorus concentration was observed in the mustard plant (Table 4.9). However, the highest concentration of phosphorus in the mustard plant (0.4760 %) was recorded with the $P_{60}S_{50}$ (60 kg P ha^{-1} + 50 kg S ha^{-1}) treatment which was statistically similar with $P_{60}S_0$ (60 kg P ha^{-1} + 0 kg S ha^{-1}) treatment combination. On the other hand, the lowest phosphorus concentration in mustard plant (0.3430%) was observed in P_0S_0 treatment.

Table 4.8 Effect of S on the N, P, K and S contents in mustard plant

Treatments	Total N (%)	Total P (%)	Total K (%)	Total S (%)
S_0	0.1365	0.4112	4.964	0.1310
S_{15}	0.1116	0.4296	5.077	0.1456
S_{30}	0.1399	0.4175	5.002	0.1851
S_{50}	0.1170	0.4170	5.160	0.2362
$LSD_{0.01}$	**NS**	**NS**	**NS**	**NS**
CV (%)	**3.96**	**1.28**	**0.89**	**3.06**

4.11 Total potassium content in mustard plant

4.11.1 Effect of P on potassium content in mustard plant

Application of P showed insignificant variation on the potassium concentration in mustard plant (Table 4.7). The highest potassium concentration in mustard plant (0.516%) was recorded in P_{40} (40 kg P ha^{-1}) treatment. On the other hand, the lowest potassium concentration in mustard plant (0.485%) was recorded in the P_0 treatment where no P was applied. The highest potassium concentration was observed due to the positive effect of potassium on potassium content in mustard plant up to certain limit.

4.11.2 Effect of S on potassium content in mustard plant

A statistically insignificant variation was observed on potassium concentration in mustard plant with different doses of sulphur (Table 4.8). However, the highest K concentration (5.160 %) among the different doses of sulphur was recorded in S_{50} (50 kg S ha^{-1}). On the other hand, the lowest K concentration in mustard plant (4.964 %) was recorded in the S_0 treatment where no S was applied. The highest K concentration was observed due to the positive effect of sulphur on K content in mustard plant up to certain limit.

4.11.3 Interaction effect of P and S on Potassium content in mustard plant

Significant effect of combined application of different doses of P and S fertilizers on the K concentration was observed in the mustard plant (Table 4.9). The highest concentration of K in the mustard plant (5.330%) was recorded with the $P_{40}S_{50}$ (40 kg P ha^{-1} + 50 kg S ha^{-1}). On the other hand, the lowest K concentration (4.630%) in mustard plant was observed in P_0S_0 treatment. This might be due to the fact that, the combined effect of both phosphorus and sulphur played positive effect on K content in mustard plant up to certain limit.

4.12 Total sulphur content in mustard plant

4.12.1 Effect of P on sulphur content in mustard plant

Application of P showed insignificant variation on the sulphur concentration in mustard plant (Table 4.7). The highest sulphur concentration in mustard plant (0.187%) was recorded in P_0 (0 kg P ha^{-1}) treatment. On the other hand, the lowest sulphur concentration in mustard plant (0.161%) was recorded in the P_{40} treatment.

4.12.2 Effect of S on sulphur content in mustard plant

The effect of different doses of sulphur showed statistically insignificant difference on the sulphur concentration in mustard plant (Table 4.8). The highest sulphur concentration among the treatments of sulphur (0.2362 %) was observed in S_{50} (50 kg S ha^{-1}). On the other hand, the lowest sulphur concentration in mustard plant (0.1310 %) was observed in the S_0 (control condition) treatment. The highest sulphur concentration was observed due to the positive effect of sulphur on sulphur content in mustard plant up to certain limit.

4.12.3 Interaction effect of P and S on sulphur content in mustard plant

Significant effect of combined application of different doses of P and S fertilizers on the sulphur concentration was observed in the mustard plant (Table 4.9). The highest concentration of sulphur in the mustard plant (0.2550%) was recorded with the $P_{60}S_{50}$

Table 4.9 Interaction effects of P and S on the N, P, K and S contents in mustard plant

Treatments	Total Nitrogen (%)	Total Phosphorus (%)	Total Potassium (%)	Total Sulphur (%)
P_0S_0	0.1260 f	0.3430 m	4.630 k	0.1340 kl
P_0S_{15}	0.112 gh	0.3770 k	4.830 i	0.1550 g
P_0S_{30}	0.1270 ef	0.3840 j	4.710 j	0.2180 c
P_0S_{50}	0.1320 def	0.3700 l	5.190 d	0.2440 b
$P_{20}S_0$	0.1420 c	0.3940 i	5.043 f	0.1380 j
$P_{20}S_{15}$	0.1020 i	0.4270 f	4.977 h	0.1480 h
$P_{20}S_{30}$	0.1603 a	0.4130 h	5.010 g	0.1660 f
$P_{20}S_{50}$	0.1170 g	0.3980 i	5.130 e	0.2130 d
$P_{40}S_0$	0.1510 b	0.4407 e	4.970 h	0.1250 m
$P_{40}S_{15}$	0.1270 ef	0.4450 d	5.290 b	0.1370 jk
$P_{40}S_{30}$	0.1370 cd	0.3980 i	5.070 f	0.1450 hi
$P_{40}S_{50}$	0.1070 hi	0.4180 g	5.330 a	0.2410 b
$P_{60}S_0$	0.1270 ef	0.4750 a	5.250 c	0.1333 l
$P_{60}S_{15}$	0.1137 g	0.4620 c	5.130 e	0.1440 i
$P_{60}S_{30}$	0.1327 de	0.4690 b	5.193 d	0.1970 e
$P_{60}S_{50}$	0.1070 hi	0.4760 a	4.970 h	0.2550 a
$LSD_{0.05}$	**0.005655**	**0.004050**	**0.009309**	**0.003335**
CV (%)	**2.69**	**0.58**	**0.32**	**1.14**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

(60 kg P ha^{-1} + 50 kg S ha^{-1}). On the other hand, the lowest sulphur concentration (0.1250%) in mustard plant was observed in $P_{40}S_0$ treatment.

4.13 Protein content in mustard seed

4.13.1 Effect of P on protein content in mustard seed

A statistically insignificant variation was observed in protein content in seed of mustard with different doses of phosphorus (Table 4.10). Among the different doses of phosphorus the highest protein content in seed (0.8194 %) was recorded in P_{40} (40 kg P ha^{-1}) treatment. On the other hand, the lowest protein content in seed (0.7470%) was recorded in the P_{60} treatment. This may be due to the suppressive effect of high P dose on the protein content in the mustard seed.

Table 4.10 Effect of P on protein and oil content of mustard

Treatment	Protein content (%)	Oil content (%)
P_0	0.7808	41.47
P_{20}	0.8090	41.53
P_{40}	0.8194	41.32
P_{60}	0.7470	41.97
$Lsd_{0.01}$	**NS**	**NS**
CV (%)	**3.96**	**0.01**

4.13.2 Effect of S on protein content in mustard seed

The effect of different doses of sulphur showed statistically insignificant variation on the protein content in seed of mustard (Table 4.11). The highest protein content in seed 0.8741 % among different doses of S fertilizers was recorded with S_{30} (30 kg S ha^{-1})

treatment. On the other hand, the lowest protein content (0.6975 %) was observed in the S_{15} treatment.

Table 4.11 Effect of S on protein and oil content of mustard

Treatments	Protein (%)	Oil (%)
S_0	0.8532	41.81
S_{15}	0.6975	41.42
S_{30}	0.8741	41.82
S_{50}	0.7314	41.25
$LSD_{0.01}$	**NS**	**NS**
CV (%)	**3.96**	**0.01**

4.13.3 Interaction effect of P and S on protein content in mustard seed

Significant effect of combined application of different doses of P and S fertilizers on the protein content was observed in seed of mustard (Table 4.12). The highest protein content in the seed (1.003%) was recorded with the $P_{20}S_{30}$ (20 kg P ha^{-1} + 30 kg S ha^{-1}) treatment which was statistically similar with $P_{40}S_0$ treatment. On the other hand, the lowest protein content (0.6298%) in seed was observed in $P_{20}S_{15}$ treatment.

4.14 Oil content in mustard seed

4.14.1 Effect of P on oil content in mustard seed

A statistically insignificant variation was observed in oil content in seed of mustard with different doses of phosphorus (Table 4.10). Among the different doses of phosphorus the highest oil content in seed (41.97 %) was recorded in P_{60} (60 kg P ha^{-1}) treatment. On the other hand, the lowest oil content in seed (41.32%) was recorded in the P_{40} treatment.

4.14.2 Effect of S on oil content in mustard seed

The effect of different doses of sulphur showed statistically insignificant variation on the oil content in seed of mustard (Table 4.11). The highest oil content in seed (41.82 %) among different doses of S fertilizers was recorded with S_{30} (30 kg S ha^{-1}) treatment. On the other hand, the lowest oil content (41.25 %) was observed in the S_{50} treatment.

4.14.3 Interaction effect of P and S on oil content in mustard seed

Significant effect of combined application of different doses of P and S fertilizers on the oil content was observed in seed of mustard (Table 4.12). The highest oil content in the seed (42.33%) was recorded with the $P_{60}S_{30}$ (60 kg P ha^{-1} + 30 kg S ha^{-1}) treatment. On the other hand, the lowest oil content (40.96%) in seed was observed in P_0S_{15} treatment.

Table 4.12 Interaction effect of P and S on protein and oil content of mustard

Treatments	Protein content (%)	Oil content (%)
P_0S_0	0.8069 bcd	42.02 bc
P_0S_{15}	0.6923 ef	40.96 i
P_0S_{30}	0.8069 bcd	41.93 bc
P_0S_{50}	0.8173 bcd	40.97 i
$P_{20}S_0$	0.8590 bc	41.89 cd
$P_{20}S_{15}$	0.6298 f	40.97 i
$P_{20}S_{30}$	1.003 a	41.59 ef
$P_{20}S_{50}$	0.7444 de	41.68 de
$P_{40}S_0$	0.9402 a	41.17 hi
$P_{40}S_{15}$	0.7860 cd	41.56 ef
$P_{40}S_{30}$	0.8694 b	41.42 fg
$P_{40}S_{50}$	0.6819 ef	41.12 hi
$P_{60}S_0$	0.8069 bcd	42.17 ab
$P_{60}S_{15}$	0.6819 ef	42.17 ab
$P_{60}S_{30}$	0.8173 bcd	42.33 a
$P_{60}S_{50}$	0.6819 ef	41.23 gh
$LSD_{0.05}$	**0.07011**	**0.2245**
CV (%)	**3.96**	**0.01**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

4.15 Effect of phosphorus on nutrient status of the post harvest soil of mustard field

4. 15.1 Effect of phosphorus on total nitrogen content in the post harvest soil of mustard field

A statistically insignificant variation was observed in nitrogen concentration in soil of mustard field with different doses of P (Table 4.13). Considering the different doses of P the highest nitrogen concentration in soil (0.08016 %) was recorded in P_{40} (40 kg P ha^{-1}) treatments. On the other hand, the lowest nitrogen concentration in soil (0.07357 %) was recorded in the P_0 treatment where no phosphorus was applied.

4. 15.2 Effect of phosphorus on available potassium content in the post harvest soil of mustard field

A statistically insignificant variation was observed in K concentration in soil of mustard field with different doses of P (Table 4.13). Considering the different doses of P the highest K concentration in soil (0.01503 ppm) was recorded in P_{60} (60 kg P ha^{-1}). On the other hand, the lowest K concentration in soil (0.01350 ppm) was recorded in the P_0 treatment where no phosphorus was applied.

4. 15.3 Effect of phosphorus on available phosphorus content in the post harvest soil of mustard field

A statistically significant variation was observed in phosphorus concentration in soil of mustard field with different doses of P (Table 4.13). Considering the different doses of P the highest phosphorus concentration in soil (21.40 ppm) was recorded in P_{60} (60 kg P ha^{-}

^{1}) which was statistically similar with P_{40} treatment. On the other hand, the lowest phosphorus concentration in soil (16.75 ppm) was recorded in the P_0 treatment where no phosphorus was applied.

4. 15.4 Effect of phosphorus on available sulphur content in the post harvest soil of mustard field

A statistically insignificant variation was observed in sulphur concentration in soil of mustard field with different doses of P (Table 4.13). Considering the different doses of P the highest phosphorus concentration in soil (9.673 ppm) was recorded in P_{40} (40 kg P ha^{-1}). On the other hand, the lowest sulphur concentration in soil (8.423 ppm) was recorded in the P_{60} treatment.

4. 15.5 Effect of phosphorus on organic matter content in the post harvest soil of mustard field

A statistically insignificant variation was observed in organic matter concentration in soil of mustard field with different doses of P (Table 4.13). Considering the different doses of P the highest organic matter concentration in soil (1.208%) was recorded in P_{20} (20 kg P ha^{-1}). On the other hand, the lowest organic matter concentration in soil (1.125 %) was recorded in the P_0 treatment where no phosphorus was applied.

Table 4.13 Effect of P on the total N, available P, available K, available S and total organic matter content of the post harvest soil

Treatment	Total nitrogen (%)	Available phosphorus (ppm)	Available potassium (ppm)	Available sulfur (ppm)	Total organic matter (%)
P_0	0.07357	16.75 c	0.01350	8.863	1.125
P_{20}	0.07831	18.08bc	0.01423	9.328	1.208
P_{40}	0.08016	19.78ab	0.01472	9.673	1.174
P_{60}	0.07835	21.40 a	0.01503	8.423	1.164
$LSD_{0.01}$	**NS**	**2.277**	**NS**	**NS**	**NS**
CV (%)	**3.96**	**1.28**	**0.89**	**3.06**	**1.08**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

4.16 Effect of sulphur on nutrient status of the post harvest soil of mustard field

4. 16.1 Effect of sulphur on total nitrogen content in the post harvest soil of mustard field

The effect of different doses of sulphur fertilizers showed a statistically insignificant variation in the nitrogen concentration in post harvest soil (Table 4.14). Among the different treatments, S_0 (0 kg S ha^{-1}) showed the highest nitrogen concentration (0.08280 %) in soil. The lowest nitrogen concentration (0.07338%) in soil was observed in the treatment S_{15}.

4. 16.2 Effect of sulphur on available phosphorus content in the post harvest soil of mustard field

The effect of different doses of sulphur fertilizers showed a statistically insignificant variation in the phosphorus concentration in post harvest soil (Table 4.14). Among the different treatments, S_{15} (15 kg S ha^{-1}) showed the highest P concentration (19.12 ppm) in soil. The lowest P concentration (18.83 ppm) in soil was observed in the treatment S_{30}.

4. 16.3 Effect of sulphur on available potassium content in the post harvest soil of mustard field

The effect of different doses of sulphur fertilizers showed a statistically insignificant variation in the K concentration in post harvest soil (Table 4.14). Among the different treatments, S_{30} (30 kg S ha^{-1}) showed the highest K concentration (0.1452 ppm in soil. The lowest K concentration (0.1426 ppm) in soil was observed in the treatment S_{15} where no S fertilizer was applied.

4. 16.4 Effect of sulphur on available sulphur content in the post harvest soil of mustard field

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the sulphur concentration in post harvest soil (Table 4.14). Among the different treatments, S_{50} (50 kg S ha^{-1}) showed the highest sulphur concentration (12.77 ppm) which was statistically similar with S_0 treatment in soil. The lowest sulphur concentration (4.156 ppm) in soil was observed in the treatment S_{15}.

Table 4.14 Effect of S on the total N, available P, available K, available S and organic matter contents of the post harvest soil

Treatment	Total nitrogen %)	Available phosphorus (ppm)	Available potassium (ppm)	Available sulfur (ppm)	Total organic matter (%)
S_0	0.08280	18.94	0.1434	10.97 a	1.203
S_{15}	0.07338	19.12	0.1426	4.156 c	1.138
S_{30}	0.07827	18.83	0.1452	8.391 b	1.155
S_{50}	0.07594	19.11	0.1435	12.77 a	1.174
$LSD_{0.01}$	**NS**	**NS**	**NS**	**1.952**	**NS**
CV (%)	**1.72**	**0.11**	**o.58**	**1.58**	**1.08**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

4. 16.5 Effect of sulphur on organic matter content in the post harvest soil of mustard field

The effect of different doses of sulphur fertilizers showed a statistically insignificant variation in the organic matter concentration in post harvest soil (Table 4.14). Among the different treatments, S_0 (0 kg S ha^{-1}) showed the highest organic matter concentration (1.203%) in soil. The lowest organic matter concentration (1.138%) in soil was observed in the S_{15} treatment.

4.17 Interaction effect of phosphorus and sulphur on nutrient status of the post harvest soil of mustard field

4.17.1 Interaction effect of phosphorus and sulphur on total nitrogen content of the post harvest soil of mustard field

Significant effect of combined application of different doses of P and S fertilizers on the nitrogen concentration was observed in post harvest soil of mustard field (Table 4.15). The highest concentration of nitrogen (0.093%) in the post harvest soil was recorded with the $P_{20}S_0$ (20 kg P ha^{-1} + 0 kg S ha^{-1}) treatment. On the other hand, the lowest nitrogen concentration (0.05593%) in the post harvest soil was observed in $P_{20}S_{50}$ treatment.

4.17.2 Interaction effect of phosphorus and sulphur on available phosphorus content of the post harvest soil of mustard field

Significant effect of combined application of different doses of P and S fertilizers on the phosphorus concentration was observed in post harvest soil of mustard field (Table 4.15). The highest concentration of phosphorus (22.53 ppm) in the post harvest soil was recorded with the $P_{60}S_{15}$ (60 kg P ha^{-1} + 15 kg S ha^{-1}) treatment. On the other hand, the lowest phosphorus concentration (16.50 ppm) in the post harvest soil was observed in P_0S_{30} treatment.

4.17.3 Interaction effect of phosphorus and sulphur on available potassium content of the post harvest soil of mustard field

Significant effect of combined application of different doses of P and S fertilizers on the K concentration was observed in post harvest soil of mustard field (Table 4.15). The highest concentration of K (0.1540 ppm) in the post harvest soil was recorded with the $P_{60}S_0$ (60 kg P ha^{-1} + 0 kg S ha^{-1}) treatment. On the other hand, the lowest phosphorus concentration (0.1300 ppm) in the post harvest soil was observed in P_0S_{15} treatment.

4.17.4 Interaction effect of phosphorus and sulphur on available sulphur content of the post harvest soil of mustard field

Significant effect of combined application of different doses of P and S fertilizers on the sulphur concentration was observed in post harvest soil of mustard field (Table 4.15). The highest concentration of sulphur (18.30 ppm) in the post harvest soil was recorded with the $P_{40}S_{50}$ (40 kg P ha^{-1} + 50 kg S ha^{-1}) treatment. On the other hand, the lowest sulphur concentration (3.317 ppm) in the post harvest soil was observed in $P_{60}S_{15}$ treatment.

Table 4.15 Interaction effect of P and S on the total N, available P, available K, available S and total organic matter contents of the post harvest soil

Treatments	Total Nitrogen (%)	Available Phosphorus (ppm)	Available Potassium (ppm)	Available Sulphur (ppm)	Total Organic matter (%)
P_0S_0	0.07303 fg	16.60 n	0.1337 j	8.367 g	1.083 g
P_0S_{15}	0.06310 j	16.93 l	0.1300 k	5.660 i	1.073 gh
P_0S_{30}	0.06897 h	16.50 o	0.1350 j	5.777 i	1.047 i
P_0S_{50}	0.08903 b	16.77 m	0.1413 h	15.60 c	1.280 b
$P_{20}S_0$	0.09300 a	18.03 i	0.1400 h	16.70 b	1.317 a
$P_{20}S_{15}$	0.07527 f	17.40 k	0.1403 h	3.447 k	1.133 f
$P_{20}S_{30}$	0.08890 b	17.70 j	0.1507 b	7.877 h	1.280 b
$P_{20}S_{50}$	0.05593 k	19.10 h	0.1380 i	9.227 f	1.087 g
$P_{40}S_0$	0.07897 e	20.10 d	0.1460 f	5.577 i	1.157 e
$P_{40}S_{15}$	0.08893 b	19.47 g	0.1503 bc	4.177 j	1.277 b
$P_{40}S_{30}$	0.07297 g	19.80 e	0.1480 de	10.50 e	1.087 g
$P_{40}S_{50}$	0.07967 e	19.63 f	0.1437 g	18.30 a	1.160 e
$P_{60}S_0$	0.08607 c	20.87 c	0.1540 a	13.10 d	1.237 c
$P_{60}S_{15}$	0.06613 i	22.53 a	0.1490 cd	3.317 k	1.057 hi
$P_{60}S_{30}$	0.08210 d	21.20 b	0.1467 ef	9.310 f	1.193 d
$P_{60}S_{50}$	0.07903 e	20.80 c	0.1500 bc	7.877 h	1.157 e
$LSD_{0.05}$	**0.002237**	**0.07457**	**0.001395**	**0.2416**	**0.02174**
CV (%)	**1.72**	**0.21%**	**0.58%**	**1.58**	**1.11**

In a column figures having similar letter(s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT

4. 17.5 Interaction effect of phosphorus and sulphur on total organic matter content of the post harvest soil of mustard field

Significant effect of combined application of different doses of P and S fertilizers on the organic matter concentration was observed in post harvest soil of mustard field (Table 4.15). The highest concentration of organic matter (1.317%) in the post harvest soil was recorded with the $P_{20}S_0$ (20 kg P ha^{-1} + 0 kg S ha^{-1}) which. On the other hand, the lowest organic matter concentration (1.047 %) in the post harvest soil was observed in P_0S_{30} treatment.

CHAPTER 5
SUMMARY AND CONCLUSION

Chapter 5

SUMMARY AND CONCLUSION

An experiment was conducted at the Sher-e-Bangla Agricultural University Farm Dhaka-1207 (Tejgaon series under AEZ No.28) during the *rabi* season of 2010-11 to study the "Role of Phosphorus and Sulphur on the growth, yield and oil content of Mustard". The soil was clay loam in texture having pH 5.8 and organic matter content of 1.05%. Two factors Randomized Complete Block Design was followed with 16 treatment combinations having unit plot size of 2.5 m x 2.0 m (5.0 m^2) and replicated thrice. Two factors were phosphorus and sulphur. The treatments were $P_0 S_0$= Control (Without P and S), $P_{20}S_0$ (20 kg P ha^{-1} + 0 kg S ha^{-1}), $P_{40}S_0$ (40 kg P ha^{-1} + 0 kg S ha^{-1}), $P_{60}S_0$ (60 kg P ha^{-1} + 0 kg S ha^{-1}), P_0S_{15} (0 kg P ha^{-1} + 15 kg S ha^{-1}), $P_{20}S_{15}$ (20 kg P ha^{-1} + 15 kg S ha^{-1}), $P_{40}S_{15}$ (40 kg P ha^{-1} + 15 kg S ha^{-1}), $P_{60}S_{15}$ (60 kg P ha^{-1} + 15 kg S ha^{-1}), P_0S_{30} (0 kg P ha^{-1} + 30 kg S ha^{-1}), $P_{20}S_{30}$ (20 kg P ha^{-1} + 30 kg S ha^{-1}), $P_{40}S_{30}$ (40 kg P ha^{-1} + 30 kg S ha^{-1}), $P_{60}S_{30}$ (60 kg P ha^{-1} + 30 kg S ha^{-1}), P_0S_{50} (0 kg P ha^{-1} + 50 kg S ha^{-1}), $P_{20}S_{50}$ (20 kg P ha^{-1} + 50 kg S ha^{-1}), $P_{40}S_{50}$ (40 kg P ha^{-1} + 50 kg S ha^{-1}), $P_{60}S_{50}$ (60 kg P ha^{-1} + 50 kg S ha^{-1}).

Recommended doses of N, K, Zn and B (120 kg N from urea, 40 kg K from MOP, 2 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.

Mustard seeds were sown on the November 5, 2010 in lines following the recommended line to line distance of 30 cm and plant to plant distance of 5 cm and the crop was harvested on February 19, 2011. The data were collected plot wise for plant height (cm), number of primary branches /plant, number of siliqua/plant, length of siliqua (cm), number of seeds /siliqua, thousand seed weight (g), seed yield (t ha^{-1}) and stover yield (t ha^{-1}).

The post harvest soil samples from 0-15 cm depth plot wise were collected and analyzed for total N, available P, available S, available K and total organic matter contents. Plant samples were also chemically analyzed for total N, P, K and S contents. Protein content and oil content of mustard seed were also determined. 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 siliqua per plant, length of siliqua, number of seeds per siliqua, thousand seed weight (g) and seed yield (t ha^{-1}) except number of primary branches per plant and stover yield (t ha^{-1}). 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 (116.7 cm) was found in $P_{60}S_{50}$ treatment, which was higher over control treatment (100 cm). Number of siliqua per plant was found maximum (108.7) in $P_{40}S_{15}$ and minimum (69.93) in $P_{20}S_{50}$ treatment. Number of seed per siliqua, length of siliqua, weight of thousand seed, seed yield were highest in P_0S_{50} (23.11), $P_{60}S_{30}$ (6.74 cm), $P_{60}S_0$(3.23 gm), $P_{60}S_{15}$ (2.86 ton/ha) respectively and the lowest was recorded in $P2_0S_{30}$ (17.32), P_0S_0 (6.27 cm), $P_{20}S_0$ (2.31 gm), $P_{20}S_0$ (1.61 ton/ha), respectively.

No 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 @ 60 kg ha^{-1} (P_{60}) produced the tallest plant (110.1 cm), whereas application of S @ 50 kg ha^{-1} (S_{50}) produced the tallest plant of 110.2 cm height. Like all other character the individual application of P @ 60 kg ha^{-1} (P_{60}) produced maximum primary branch (5.77), whereas application of S @ 15 kg ha^{-1} (S_{15}) produced the maximum primary branch (5.73). The remaining character such as number of siliqua per plant, length of siliqua, number of seeds per siliqua, thousand and seed weight (g) showed highest result in P_{40} (91.75), P_{60} (6.66 cm), P_{60} (3.003), P_{60} (2.44 ton/ha), respectively.

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 (2.86 t ha^{-1}) was recorded in $P_{60}S_{15}$ treatment. The lowest yield (1.61 t ha^{-1}) was recorded in $P_{20}S_0$ treatment. Combined application of P @ 60 kg ha^{-1} and S @ 15 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.

Protein content in seeds of mustard was significantly increased due to combined application of P and S. The range of protein content in mustard seeds varied from 0.62% in $P_{20}S_{15}$ treatment to 1.003% in $P_{20}S_{30}$. Application of P @ 20 kg ha^{-1} and S @ 30 kg ha^{-1} produced higher protein content in seed compared to control treatment significantly.

Oil content in seeds of mustard was significantly increased due to application of P and S. The range of oil content in seeds varied from 40.96% in P_0S_{15} to 42.33% in $P_{60}S_{30}$ treatment. Application of P @ 60 kg ha^{-1} and S @ 30 kg ha^{-1} produced higher oil content in seed compared to other treatments significantly.

Nutrient contents (N, P, K and S) in plant samples were positively affected due to P and S fertilization. The interaction effect of P and S was also found remarkable. The N, P, K and S contents in plant samples varied from 0.102% in $P_{20}S_{15}$ treatment to 0.16% in $P_{20}S_{30}$ treatment, 0.34% in P_0S_0 treatment to 0.476% in $P_{60}S_{50}$ treatment, 4.63% in P_0S_0 treatment to 5.33% in $P_{40}S_{50}$ treatment and 0.12% in $P_{40}S_0$ treatment to 0.25% in $P_{60}S_{50}$ treatment, respectively. Nitrogen, Phosphorus, Potassium and Sulphur contents in plant samples increased with increasing levels of P and S up to a certain level.

Nutrient content in post harvest soil was also influenced by different levels of P and S application. The total N, available P, available K, available S and total organic matter content of post harvest soil varied from 0.055% to 0.093%, 16.50 ppm to 22.53 ppm, 0.130 ppm to 0.154 ppm, 3.31 ppm to 18.30 ppm and 1.04% to 1.32%, respectively due to combined application of P and S at different levels. The addition of P and S not only increased the yield but also protected the soil from total exhaustion of nutrients.

Considering all the parameters studied the following conclusion may be drawn:-

Significantly higher growth and yield performance, protein and oil content of mustard was observed in the $P_{60}S_{15}$ treatment i.e by the combined application of P and S fertilizers @ 60 kg P ha^{-1} and 15 kg S ha^{-1}, respectively.

Based on the results of the present study, the following recommendation may be drawn:-

The combined application of P and sulphur fertilizers @ 60 kg P ha^{-1} and 15 kg S ha^{-1} may be done in Tejgaon series under AEZ No.28 to get higher yield, protein and oil content of mustard and also to maintain soil fertility and productivity than their individual applications.

However, to reach a specific conclusion and recommendation, more research work on mustard should be done in different Agro- ecological zones of Bangladesh.

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Figure 3. Field view of the experimental plot at 90 DAS