RESPONSE OF MAIZE TO PHOSPHORUS AND SULPHUR FERTILIZATION

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CERTIFICATE

This is to certify that thesis entitled, "*RESPONSE OF MAIZE TO PHOSPHORUS AND SULPHUR FERTILIZATION*" submitted to the *DEPARTMENT OF SOIL SCIENCE*, Sher-e-Bangla Agricultural University, Dhaka in partial fulfilment of the requirements for the degree of *MASTER OF SCIENCE (M.S.)* in *SOIL SCIENCE* embodies the result of a piece of bona fide research work carried out by *MD. SAKIB SIDDIQUE* Registration No. *02162* under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated...30/12/07.........

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Dedicated To My

Beloved Parents

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ABSTRACT

A field experiment was conducted at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the *rabi* season of 2006-07 to study the response of maize to phosphorus and sulphur fertilization. The experimental soil was silty clay loam and the pH was 4.8. The experiment was laid out in a Randomized Complete Block Design (RCBD) with 3 (three) replications of each treatment. There were 16 treatments. The treatments consisted of 4 (four) levels of P (0, 35, 50 and 65 kg P/ha) designated as P_0, P_{35}, P_{50} and P_{65}, respectively and 4 (four) levels of S (0, 25, 40 and 55 kg S/ha) designated as S_0, S_{25}, S_{40}, and S_{55}, respectively. TSP and Gypsum were used as the sources of phosphorus and sulphur, respectively. Phosphorus and sulphur fertilizers were applied according to fertilizer recommendation of BARI. There was a positive impact of P and S and their interaction on growth, yield and yield attributes of maize. Application of 50 kg P/ha resulted tallest plant, highest number of cobs/plant, maximum cob length, maximum grains/cob, highest circumference of cob, highest grain and stover yield, N and S uptake by plant and available P in post harvest soil. Highest values in respect of plant height, cobs/plant, cob length, grains/cob, circumference of cob, grain yield, stover yield, shelling percentage, N content in maize plant, N, K and S uptake by maize plant, organic carbon and available P in post harvest soil were obtained with 40 kg S/ha. Combined application of P and S had significant effect on plant height, number of cobs/plant, cob length, grain/cob, circumference of cob, 1000-grain weight, grain yield, stover yield, N, P, K and S content in maize plant, N, P, K and S uptake by maize plant, organic carbon and total N in post harvest soil. Phosphorus @ 50 kg/ha with sulphur @ 40 kg/ha gave the highest plant height, number of cobs/plant, cob length, grain/cob, circumference of cob, 1000-grain weight, grain yield, stover yield and S uptake by maize plant. Therefore, application of 50 kg P along with 40 kg S/ha and recommended other nutrients is the most suitable treatment combination for the efficient production of maize in the soils of the Modhupur Tract. Application of phosphorus and sulphur at their higher levels of combination showed antagonistic effects on both the concentrations and uptake of phosphorus and sulphur and on the concentration of potassium in maize plant.

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Chapter 1
INTRODUCTION

Maize (*Zea maize* L.) is one of the most important cereal crops of the world and hence it may be acceptable as a third cereal crop in Bangladesh for its higher productivity. Maize is a multi-purpose crop. Every part of the plant and its products are used in one form or other. As food, it can be consumed directly as green cob, roasted cob or popped grain. Its grain can be used for human consumption in various ways, such as, corn meal, fried grain and flour. Its grain has high nutritive value containing 66.2% starch, 11.1% protein, 7.12% oil and 1.5% minerals. Moreover, it contains 90 mg carotene, 1.8 mg niacin, 0.8 mg thiamine and 0.1 mg riboflavin per 100 g grains (Chowdhury and Islam, 1993). Maize oil is used as the best quality edible oil. The by-product of the oil extraction is valued as livestock feed. Green parts of the plant and grain are used as livestock and poultry feed. Sheaths of cobs are used to make paper of improved quality cigarettes. Stover, dry leaves, coverings of cobs and shelled cobs are used as good fuel (Ahmed, 1994). Maize has a great utility in industrial purpose for the production of pop corn syrup, soft drink, juice, beer, chewing gum, candy, chips, corn flakes and starch. Maize starch is also used as raw martial in the chemical industry, plant varnish, artificial rubber, soap and bakery. Maize has starch-rich endosperm and fat-rich embryo. Nutritionally it can be compared with rice and wheat. Maize is the staple carbohydrate food in many American, African and Asian countries. In 1999, world cereal crop production was highest as maize followed by wheat and rice, their average yields were 4.39, 2.63 and 3.75 t/ha, respectively (FAO, 1999). About 45% of the total would maize crop is grown in the United States. Other important maize growing countries are China, Brazil, Mexico, India and Thailand.

In Bangladesh, the cultivation of maize has been gaining popularity in recent years. It is now becoming an important cereal crop for its higher productivity and diversified uses (Islam and Kaul, 1986). It covers about 2429 hectares of land producing 2000 tons of grains annually (BBS, 1999). Maize crop has been included as a major enterprise in the crop diversification and intensive cropping programmes (Kaul and Rahman, 1983).

Moderate temperature of 24°C to 30°C and about 800 mm of well distributed rainfall are conducive to good growth of maize (Thakur, 1980). The agroclimatic condition of Bangladesh is favorable for its cultivation round the year. Pest and disease infestations are comparatively less in maize than in other cereals. Maize may offer a partial solution to the food shortage of Bangladesh if its present yield level and total production can be further raised. Maize can contribute significantly in this respect because of its higher productivity per unit area than wheat or rice. The problem of low grain yield of maize in our country may be associated with declining productivity of high to medium lands under continuous intensive cropping, low soil fertility thus declining at rapid rate. This problem may be overcomed by judicious application of fertilizers, especially with phosphorus and sulphur.

Phosphorus nutrition is a major consideration for increasing grain yield and quality of maize. Phosphorus should be applied in such a way that would maximize its utilization for grain production. It appears that there is a need to find out a fertilizer management system using a combination of sulphur with phosphorus fertilizer, for better utilization of the latter.

Recently sulphur deficiency has been found to be widespread in soils of Bangladesh. Intensive use of higher analysis fertilizers like urea, TSP and MP, high yielding varieties (HYV), higher cropping intensity without any replenishment and limited use of organic manures are the most probable reasons for sulphur deficiency. Sulphur deficiencies affect not only yield of crop but also protein quality through its effects on the synthesis of certain amino acids, cystine and methionine as well as plant hormones and vitamins. It is reported that significant responses of maize to S, generally in the range of 12 to 20% yield increase [Allen (1976) in Western Kenya, Grant and Rowell (1976) in Zimbabwe, and Kang and Osiname (1976) in Nigeria].

Recently farmers of Bangladesh are advised to use gypsum along with TSP for higher yield. But research on examining the best combination of phosphorus and sulphur for higher maize yield is still meager. Therefore, an attempt was made with the objective to identify the suitable doses of phosphorus and sulphur in order to achieve both quantitative and qualitative improvement of maize production. The average yield of maize in the country is not satisfactory. It is rather low compared with leading maize growing countries of the world. The national average yield is only 1.06 t/ha, whereas, the newly released varieties have the potential to produce more than 11 t/ha (BBS, 2005)

Considering the above facts the present investigation has been undertaken with the following objectives:

- to study the individual effects of phosphorus and sulphur on the yield of maize.
- to study the combined effect of phosphorus and sulphur for maximizing the yield of maize.
- to determine the appropriate doses of phosphorus and sulphur fertilizer for maximizing the yield of maize.

Chapter 2
Review of Literature

Chapter 2

REVIEW OF LITERATURE

2.1 Response of maize to phosphorus fertilization

Dhakshinamoorthy and Rani Perumal (2001) conducted a field experiment in Tamil Nadu, India to evaluate the effects of different P sources viz. single superphosphate (SSP), rock phosphate (RP), RP + coirpith compost (CPC) and diammonium phosphate (DAP), with P_2O_5 rates (30, 60, 90 and 120 kg/ha), on finger millet (first crop), maize (second crop) and black gram (third crop). Finger millet and maize were fertilized with phosphatic fertilizers while black gram was not to study the direct effect of fertilizers on finger millet, cumulative effect on maize and residual effect on black gram. Phosphorus fertilization enhanced grain and straw yields of the three crops. Water soluble sources like DAP and SSP was more advantageous in terms of crop yield and yield attributes than water insoluble sources (RP alone or in combination with CPC). However, the residual effect of RP + CPC was superior over that of other treatments.

Awan and Abbasi (2000) studied the interactive effect of phosphorus (P) and copper (Cu) on maize growth in pots. P at 0, 25, 50 mg/kg and Cu at 0, 2.5, 5 mg/kg were applied in all possible combinations to a sandy loam soil. Five plants of maize in each pot were grown to tasseling stage which received N and K at 75 and 50 mg/kg, respectively. Fresh and dry weights of maize fodder increased upon P and Cu applications but decreased at higher treatment combinations. N concentration increased with Cu application whereas, P concentration was decreased. P application increased P concentration but decreased Cu concentration in maize plants, leading to the conclusion that an interaction between P and Cu in soil occurs affecting the production of maize fodder significantly.

Prado *et al.* (2001) studied the effects and doses of phosphorus fertilizer under a maintenance of fertilizer application on a maize crop in a dark red latosol in Triangulo Mineiro, Uberaba (Minas Gerais, Brazil), from October 1995 to April 1996. The treatments consisted of the following applications of triple superphosphate: broadcasting, single furrow and double furrow and the following doses of 0, 45.0, 67.5, 90.0, 112.5 and 135.0 kg ha^{-1} of P_2O_5. Doses of P were estimated based on 0, 0.50, 0.75, 1.00, 1.25, 1.50 times the dose recommended for maintenance fertilizer application, 90 kg ha^{-1} of P_2O_5. It was found that the use of increasing P doses increased maize grain yield; the phosphorus fertilizer applications in single furrows and double furrows were more efficient than broadcasting; double furrow application was the most outstanding mode of application; foliar P content varied from 2.1 to 2.4, 2.1 to 2.7 and from 2.1 to 2.9 g kg^{-1}, respectively, for broadcasting, single furrows and double furrows. Maize yield increased from 0.45 to 3.04 t ha^{-1} for single furrows and from 0.21 to 4.4 t ha^{-1} for double furrows.

Reichbuch (1987) examined the effects of 0-200 kg N (to potatoes, sugarbeet and maize) and 0-160 kg N (to winter wheat) + 0-160 kg P_2O_5 + 0 or 100 kg K_2O/ha on soil pH and soluble P, K, Al and Fe contents of a chernozem soil at Suceava in 1968-84. Soil acidity increased with long term N applications alone or with low P rates which had a negative effect on sugar beet root and maize grain yields. Potato tuber yields increased with increase in N rate only, 20 kg N/ha were the optimum economical rate. Winter wheat grain yields ranged from 3.02 t/ha with 80 kg P_2O_5 to 4.95 t with 120 kg N + 160 kg P_2O_5; 80 kg N + 40 kg P_2O_5/ha were the most economical rate. The highest sugar beet root yields were achieved with 100-150 kg N + 120-160 kg P_2O_5 /ha. The most efficient NP rates for maize were 100-120 kg N + 120-160 kg P_2O_5/ha.

Barreto and Serpa (1988) conducted field trials at Poco Verde, Sergipe, Brazil in 1979, with maize cv. Centralmex and *Phaseolus vulgaris* cv. IPA-74119 grown in pure stands at 50 000 and 200 000 plants/ha or intercropped in a 1 row maize (25 000 plants): 3 rows *P. vulgaris* (150 000 plants/ha) arrangement. P was applied at 0-300 kg P_2O_5 /ha as superphosphate. Intercropped *P. vulgaris* yields with 0, 100, 200 and 300 kg P_2O_5 were 29, 40, 44 and 47% of pure stand yields, respectively; corresponding intercropped maize yields were 56, 87, 85 and 67% of pure stand yields. Land equivalent ratios of the intercrops were 0.85, 1.27, 1.29 and 1.14 with 0, 100, 200 and 300 kg P_2O_5, respectively. Maize showed a linear response to P in pure stands and a quadratic response when intercropped. *P. vulgaris* response was similar in both systems. Plant P concentrations of both crops was similar in both systems.

Sharma *et al.* (2002) conducted field experiments during 1998-99 and 1999-2000 at Udaipur, Rajasthan, India to study the residual effect of weed management and P applied to the preceding Indian mustard crop on the content and uptake of N and P by the succeeding fodder maize cv. G-2 crop and its weeds. The treatments applied to the preceding Indian mustard crop comprised 6 weed management practices (weedy control, hand weeding at 30 days after sowing, pre-plant incorporation of fluchloralin at 1.0 kg/ha, pendimethalin applied at 0.75 kg/ha, alachlor applied at 1.5 kg/ha and pre-emergence application of oxyfluorfen at 0.125 kg/ha) and 4 levels of P (0, 20, 40 and 60 P_2O_5/ha). There was no significant residual effect of different weed management practices on N and P uptake and concentration in weeds or the fodder maize crop, except for the increase in P and N uptake recorded during the second year. P applied to the preceding Indian mustard crop significantly increased the P content as well as N and P uptake by the succeeding fodder maize crop and its associated weeds during both years.

- Tagwira (1995) carried out greenhouse and field experiments to assess the effect of lime and phosphate application on growth, yield, and phosphorus and zinc uptake by maize grown on the two major agricultural soils of Zimbabwe. Liming improved yield where pH was below 4.8 (0.01 N $CaCl_2$) but there was generally no yield benefit in liming the soil beyond pH 5.0. In greenhouse experiments, applications of 120 and 240 kg/ha P_2O_5 increased yield very significantly. In the field experiment, results were variable. Yield response to zinc application was observed in fields which were limed or received 240 kg/ha P_2O_5. Liming increased phosphate availability and concentration in maize plants. Both lime and phosphate applications reduced concentration of zinc in maize plants.

- Sharma and Sharma (1991) added nitrogen (0, 30, 60 and 90 kg/ha) and phosphorus (0, 20, 40 and 60 kg P_2O_5/ha) fertilizers to maize cv. Vijay crops planted in Jharnapani, Nagaland, India, in an attempt to control infection by *Exserohilum turcicum* [*Setosphaeria turcica*]. At harvest, grain yield significantly increased with P levels up to 40 kg/ha followed by a decline at higher levels. The optimum combination for highest grain yield and maximum disease control was 90 kg/ha N and 40 kg/ha P_2O_5. It is concluded that a balanced dose of N and P is required for low disease incidence and optimum grain yield.

- Jiang *et al.* (2006) conducted a 20-year field experiment to (1) assess the effect of inorganic and organic nutrient sources on yield and yield trends of both winter wheat and maize; (2) monitor the changes in soil organic matter content under continuous wheat-maize cropping with different soil fertility management schemes; and (3) identify reasons for yield trends observed in Xuzhou City, Jiangsu Province, China. There were eight treatments applied to both wheat and maize: a control treatment (C); three inorganic fertilizers, that is, nitrogen (N), nitrogen and phosphorus (NP), and nitrogen, phosphorus and potassium (NPK); and addition of farmyard manure (FYM) to these four treatments, that is, M, MN, MNP, and MNPK. At the end of the experiment the MN, MNP, and MNPK treatments had the highest yields, approximately 7 tonnes wheat ha^{-1} and 7.5 tonnes maize ha^{-1}, with each approximately 1 ton ha^{-1} more than the NPK treatments. Over 20 years with FYM, soil organic matter increased by 80% compared to only 10% with NPK, which explained yield increases. However, from an environmental and agronomic perspective, manure application was not a superior strategy to NPK fertilizers. If manure was to be applied, it would be best applied to the wheat crop, which showed a better response than maize.

Arvind and Kanthaliya (2004) conducted a field experiment during 1997 to 2001-02 on Typic Ustochrept (Inceptisols) of Udaipur (Rajasthan) under the aegis of All India Coordinated Research Project on long-term fertilizer experiments with different fertilizer combinations following maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. Soil test based 100% optimum dose of N, P_2O_5 and K_2O (90:30:15) for maize and wheat showed significantly higher grain and straw or stover yields than unfertilized, 100% N, 100% NP and FYM at 20 tones ha^{-1}. Maize and wheat exhibited maximum yields by applying 100% NPK + FYM 10 tones ha^{-1} and statistical equivalence of 150% NPK. The lack of potassium in the fertilizer application schedule did not have any deleterious effect on yield, while the lack of both phosphorus and potassium, remarkably decreased the yield of crop. Like nitrogen, even phosphorus application also started to decrease crop yields from 4th cropping cycle. However, application of FYM along with NPK sustained crop yield and nutrient status of the soil.

Akinrinde *et al.* (2005) conducted investigation to evaluate the relative agronomic efficiency (RAE), phosphorus recovery (PR) and added benefits (AB) of combining organo-mineral (OM) fertilizer with Ogun rock phosphate, ORP (31.0% P_2O_5), Sokoto rock phosphate, SRP (36.0% P_2O_5) or single super phosphate, SSP (18% P_2O_5) using maize (*Zea mays*) and watermelon (*Citrullus* *lanatus*) as test crops on a medium acid Oxic Paleustalf and a weakly acid Typic Paleudalf. The soils were cropped two times after mixing with OM and/or ORP, SRP and SSP to supply P at 0, 50 and 100 mg kg^{-1}. Results showed that combined application of OM with SRP led to the highest biomass production of 2.24 g pot^{-1} of maize and 0.79 g pot^{-1} of watermelon, with tangible (positive) AB values (0.02 and 0.07, respectively) on the Oxic Paleustalf. The RAE of OM with respect to maize shoot biomass was higher (184.21%) on the Oxic Paleustalf compared with Typic Paleudalf (82.12%). For watermelon, SRP and OM+SRP produced the highest RAE of 115.5% and 127.27% on medium acid Oxic Paleustalf and weakly acid Typic Paleudalf, respectively. The magnitude of fertilizer P recoverable through the harvest of the crops was generally low (2.2-12.4%) but significantly ($P<0.05$) higher (about 10.0%) through maize production than through watermelon production (about 2.0%). The work further confirms that any of the fertilizers tested could be used as substitute for SSP while significant benefit could accrue from the application of combined OM and phosphate fertilizers to maize and watermelon when grown on either of the two soil types..

- Kale *et al.* (2005) conducted a study in Maharashtra, India, during 1993-94 to determine the effects of nitrogen and phosphorus on the growth and yield of sunflower (cv. Morden) and their residual effect on maize (cv. African tall). Treatments comprised: an untreated control (T_1); urea + single superphosphate (SSP) at 75% of the recommended NPK dose (RDF, 60:30:30 kg/ha) (T2); urea + SSP at 100% RDF (T_3); urea nitric phosphate (19:19:0) at 75% recommended dose of N and P (T_4); urea nitric phosphate (19:19:0) at 100% recommended dose of N and P (T_5); urea nitric phosphate (27:9:0) at 75% recommended dose of N and P (T_6); urea nitric phosphate (27:9:0) at 100% recommended dose of N and P (T_7); and ammonium nitro phosphate at 100% recommended dose of N and P (T_8). The decreasing trend observed for grain yield was $T_7>T_8>T_3>T_6>T_4>T_2>T_5>T_1$. The decreasing trend observed for stover yield was $T_7>T_8>T_3>T_5>T_4>T_6>T_2>T_1$. Seed protein content was highest in T_5 (15.75%). T_7 recorded the highest N (91.10 mg/plant), P (39.40 mg/plant) and K uptake (152.10 mg/plant). T_5 had the highest soil available N (170.1 kg/ha) and P (9.44 kg/ha), while T_8 had the highest soil available K (212.0 kg/ha). The amount of dry matter was highest in T_3. There was marginal increase in soil available P (14.51 kg/ha) and K (211.0 kg/ha) in T_5 and T_2, respectively, than the rest of the treatments. No residual effect of N was observed due to application of N and P sources.

- Liu *et al.* (2005) stated quantitative estimation of fertilizer requirements can help to increase maize (*Zea mays*) yields and improve the fertilizer use efficiency. The model for the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) was calibrated for maize by use of soil fertility data and fertilizer trials at different sites of the Huang Huai Hai river plain in China. The QUEFTS model accounts for interactions between nitrogen (N), phosphorus (P) and potassium (K). It describes the effects of soil characteristics on maize yields in four steps: (1) assessment of the potential supply of N, P and K based on soil chemical data; (2) calculation of the actual uptake of N, P and K, in function of the potential supply as determined in step 1; (3) draft the yield ranges as a function of the actual uptake of N, P and K as determined in step 2; and (4) calculation of the maize yield based on the three yield ranges established in step 3. Data of field experiments with different fertilizer treatments in various regions in China during 1985-95 were used to calibrate the QUEFTS model for summer maize. In step 1 the N, P and K recovered from their amount applied were described by new equations. The minimum and maximum accumulated N, P and K (kg grain kg^{-1}) in summer maize were determined as (21-64), (126-384) and (20-90), respectively. The simulated yields were in good agreement with the observed ones. It is concluded that the calibrated and adjusted QUEFTS model could be useful in improving fertilizer recommendations for maize in the Huang Huai Hai plain of China.

- Khan *et al.* (2005) conducted field experiment in Multan, Pakistan, to study the effects of different levels of phosphorus (0, 25, 50, 75 and 100 kg P_2O_5 ha^{-1}) on 2 maize cultivars (Hybrid N-6240 and Hybrid 6622) grown under saline conditions. Plant height, number of cobs per plant, number of grain rows per cob, number of grains per cob, grain weight per cob, 1000-grain weight, and stalk and grain yields significantly increased with phosphorus application. Plants supplied with 75 kg P_2O_5 ha^{-1} were superior in terms of grain weight per cob, number of grains per cob, cob weight and 1000-grain weight. The greatest plant height and number of cobs per plant were obtained with 100 kg P_2O_5 ha^{-1}, whereas the highest number of grain rows per cob was recorded 50 kg P_2O_5 ha^{-1}. The phosphorus level had no significant effect on harvest index, probably due to the better ability of heavy plants (producing greater biomass) to produce higher economic yields under saline conditions. The effects of genotype and genotype x phosphorus interaction were not significant for all the characters. Phosphorus at 75 kg P_2O_5 ha^{-1} appeared to be optimum for maize grown under saline conditions.

- Akande *et al.* (2005) evaluated the effect of rock phosphate (Sokoto and Ogun rock phosphates) amended with poultry manure on soil available phosphate (P) and yield of maize and cowpea grown sequentially for four cropping seasons. The results obtained showed superiority of single super phosphate (SSP) application over either Sokoto or Ogun rock phosphates. However, complementary application of the Sokoto and Ogun rock phosphates with poultry manure increased maize plant height by 12, 6, 19 and 8%, respectively. Also, percent phosphorus contents in maize and cowpea leaf tissues increased respectively by 33 and 22, and 22 and 25% in 2000, and by 25 and 6, and 16 and 18%, respectively in 2001. Maize grain yield was increased by 33 and 26, and 18 and 25%, respectively, while that of cowpea was increased by 25 and 32, and 49 and 38% in 2000 and 2001, respectively when compared with application of rock phosphate alone. Single super phosphate treated soil had the highest residual P values in all the three sampling periods. The effectiveness of rock phosphate as a P sources for crop production was remarkably enhanced by solubilizing effect of poultry manure. Its low rate (2 t ha^{-1}) in combination with rock phosphate gave almost similar effects like higher rates (3 and 4 t ha^{-1}) of applications.

Kruczek (2005) evaluated on the basis of a 4-year (2000-2003) study conducted in Swadzim, Poznan, Poland, the effects of maize on fertilizer application method on the content of mineral components and the utilization of phosphorus from fertilizer were evaluated. Two methods of fertilizer application were used: by broadcasting and by fertilizer application in rows. The effect on the content of mineral components was studied by increasing the fertilizer application doses from 17.4 to 56.7 kg P ha^{-1} and by the application of superphosphate and ammonium phosphate. Experiments were carried out on a parabraunerde soil type. It was found that fertilizer application in rows combined with seed sowing increases the content of phosphorus and nitrogen and raises the percentage of phosphorus utilization from fertilizer in comparison with the fertilizer application by broadcasting in the initial stage of development. Ammonium phosphate exerted a better influence on the uptake of phosphorus and nitrogen by plants and on the percentage of phosphorus uptake in comparison with superphosphate.

Zhang *et al.* (2005) studied phosphorus nutrient characteristics of 5 different maize inbred lines to low-P stress at stages of seedling, steming, earing, silking under pot culture. In the periods of seedling and steming, P uptake efficiency was the main contributor to P tolerance, and the relative P content in P-tolerant genotypes, 99180 and 99239 were higher than that in sensitive genotype, 99152. At earing stage, P-tolerant genotypes, compared to P-sensitive ones, had higher accumulation of P in upper leaves. When came to the silking stage, P uptake and redistribution efficiency of P-tolerant genotypes were higher than those in 99152. The results also suggested that there are different mechanisms of P nutrient uptake and distribution in different P-tolerant genotypes. Inbred line 99239, according to the investigation, was considered as an efficient stock in the P-uptake while 99180 fallen to the efficient stock of P redistribution.

Araujo *et al.* (2004) determined the affects of triple superphosphate, magnesium thermophosphate, Arad reactive rock phosphate and Araxa rock phosphate, applied on the whole plantation area or banded in sowing furrow at 180 kg P_2O_5, on the yield and nutrition of maize in a field experiment conducted in Minas Gerais, Brazil. Yield was higher with the application of the most soluble forms of phosphorus viz., triple superphosphate and magnesium thermophosphate on the whole plantation area and with reactive phosphate banded in the sowing furrow. Triple superphosphate applied in sowing furrow decreased the yield of the crop. Leaf analysis during the flowering stage was the most suitable for the evaluation of P and Zn balance in the crop.

Wang *et al.* (2004) grew inbred lines of maize in a field experiment and supplied with phosphorus (P) at 2 rates (10.5 and 84 kg P_2O_5/ha, respectively). Low P stress enlarged the gap between different maize genotypes in their major yield-contributing characteristics. Classification of lines on P use-efficiency based on yield reduction percentage under low P stress showed that high P use-efficient genotypes had relatively low response to P application, averaging 6.92, while the response to P was much higher in low P-efficient genotypes, averaging 25.60. Correlation analysis indicated that the yield reduction percentage showed a highly significant positive correlation with P response.

Selassie *et al.* (2003) conducted field and laboratory experiments to develop equations for estimating phosphorus fertilizer requirements of maize on Alfisols of Northwestern Ethiopia. The field experiment on 20 sites was arranged in randomized complete block design with five fertilizer rates (0, 30, 60, 90 and 150 kg P_2O_5/ha) and four replications. At maturity, three central rows were harvested and yield and yield component data were collected. Laboratory analysis of soil samples was conducted following chemical soil analysis methods: Bray-1, Bray-2, Olsen, Mehlich-1, anion exchange resin and extraction with 0.01N $CaCl_2$. Parameters of the quantity/intensity relationships were also determined. Reliable methods were identified by fitting relative grain; relative dry biomass and P yields in a double log curvilinear regression model and those availability indices giving superior correlation were selected. Consequently, grain yield data and phosphorus availability indices were fitted into the Mitscherlich-Bray model to develop fertilizer recommendation equations. Among the methods giving quantity of available P, Bray-2 and Olsen methods gave the most reliable indices. Moreover, the intensity parameters in combination with the quantity parameters gave slightly superior correlation coefficient with yield parameters compared with their individual effects. The equations developed for estimating P fertilizer requirements of maize from soil analysis were: (a) log (100-y)=2-0.1468b-0.007546x and (b) log (100-y)=2-0.1167b-0.007546x for Olsen and Bray-2 methods, respectively, where y was desired relative grain yield (%); b was soil P availability index (mg kg^{-1}); and x was P fertilizer requirement (kg ha^{-1}). The two equations were statistically proven to provide equally reliable estimates of P fertilizer requirement of maize on Alfisols of Northwestern Ethiopia.

Kruczek and Szulc (2004) stated that as a result of row application of a fertilizer at sowing time, a significantly higher infestation of maize (*Zea mays*) plants by fusariosis than in case of broadcast fertilizer application. Using polidap, the infestation of maize by fusariosis increased as compared to superphosphate. As rates of phosphorus increased from 40 to 130 kg P_2O_5 ha^{-1}, percent invasion by flit fly plants gradually increased from 4.9%, in the case of rate 40 kg P_2O_5 ha^{-1} and to 6.6% when rate of 130 kg P_2O_5 ha^{-1} was used. Using polidap increased the percentage of invasion by flit fly as compared to superphosphate. Row fertilizer application at sowing time increased the percentage of plant invasion by flit fly as compared to broadcast fertilizer application.

Li-Shao Chang *et al.* (2004) planted maize variety KH5 with high phosphorus use efficiency (HPE) and the low efficient (LPE) variety Xi502 in sand. Pots were supplied with P at a low rate (Pi of 25 micro mol/litre) and normal rate (Pi of 2 m mol/litre). The HPE variety exhibited higher N and K uptake efficiency in the low P regime. Its nitrogen (N) and potassium (K) uptake and dry matter accumulation were less affected by low P supply. With lower P rate, N and K uptake by plants and dry matter production of the LPE variety were much lower than that of HPE, though the LPE variety had significantly higher N and K uptake and dry matter accumulation when grown under normal P regime. Low P supply induced an increase in dry matter accumulation rate and N and K distribution in the roots, and this trend was more striking in the LPE variety, indicating its lower tolerance to low P stress.

Thind *et al.* (2003) carried out a screenhouse study to evaluate the relative efficiency of five methods viz., Olsen, Bray, Morgan, Double acid and $CaCl_2$ for determining P availability to winter maize (*Zea mays* cv. Partap). Twenty nine alluvial soils from Ludhiana, Punjab, India, varying in available P status were used to grow the crop for 60 days with P applied at 10, 20, 30 and 40 mg/kg soil. Phosphorus extracted with Olsen's method (0.5 M $NaHCO_3$, pH 8.5) showed the highest correlation with crop dry matter yield (r=0.72*). A value of 5.5 mg P/kg soil determined with this method was found to be the critical deficiency level below which maize may respond to P application.

Kumaresan *et al.* (2003) conducted a field experiment during 1997-98 and 1998-99 in Tamil Nadu, India, to determine the phosphorus (P) balance in a maize-sunflower-cowpea fodder cropping system. P sources used in the main plots were

Mussoorie rock phosphate (MRP) + microbial inoculants, MRP alone, single superphosphate (SSP) + microbial inoculants and SSP alone, while in subplots, 50, 75 and 100% recommended level of P_2O_5 were used. The P_2O_5 uptake was higher in the treatment with SSP + microbial inoculants followed by SSP alone. The recommended level of P_2O_5 when applied for all the crops in the system increased the P_2O_5 uptake which was attributed to increase soil available P_2O_5. The P_2O_5 application also showed a theoretical positive balance.

Simonete *et al.* (2003) studied the effect of sewage sludge on the chemical properties of a Red-Yellow Pozolic soil (Ultisol), and on nutrient accumulation and dry matter yield of maize plants. The experiment was carried out in a greenhouse, in a completely randomized design and treatments were arranged in a 6x2x2 factorial. Soil (3 kg) inside pots was treated with 0, 10, 20, 30, 40 and 50 tones ha^{-1} (dry-basis) of sludge. Thirty days after incubation, soil samples were taken for analysis, complementation with P (0 and 100 Mg ha^{-1}) and K (0 and 100 Mg ha^{-1}) was done and five maize plants were grown in each pot for 50 days. The application of sewage sludge increased organic matter, P, K, Ca, Mg, S, Al and H+Al and reduced the pH. The accumulation of nutrients and dry matter yield were higher with sewage sludge application and increased with the application of K, but not with the application of phosphorus.

Shiluli *et al.* (2003) conducted experiments in farmers' fields in 2 locations (Lihanda and Jina) in western Kenya from 1994 to 1996 to determine the agronomic and economic benefits of applying nitrogen (N) and phosphorus (P) to maize. The soils were well-drained sandy clay loams of moderate to high fertility. Treatments comprised four N levels (0, 30, 60 and 90 kg/ha, applied as urea) combined with three P levels (0, 40 and 80 kg/ha, applied as triple superphosphate). Statistical analyses of yield data revealed that N application consistently affected grain yield significantly at both locations. P had a significant effect on yield once at each location. There was significant N x P interaction effects once at each location. Analysis across sites showed that N and interactions were statistically significant. The statistically significant treatments were subjected to economic analysis using the partial budget procedure to determine the N: P rates that would give acceptable returns at low risk to farmers. Economic analysis on the interaction across location showed that two N:P combinations, i.e. 30:0 and 60:40 kg/ha, were economically superior and stable within a price variability range of 20%..

Alexandrova and Donov (2003) conducted a field experiment on leached Smolnitza soil during 1982-1987 at Sredec, Stara Zagora region, Pakistan, to study the response of two maize hybrids (300 and 700 FAO) to five levels of nitrogen (0, 302, 242, 182, 121 kg N ha^{-1}) and phosphorus (0, 65, 52, 39, 26 kg P ha^{-1}). Plant samples were evaluated for dry biomass and total nitrogen content at 14 days after germination. The uptake of nitrogen was evaluated based on these parameters. During the vegetative period, some meteorological parameters that influence maize growth, and N content and uptake were measured daily (at 7.00, 14.00 and 21.00 h). Regression equations describing the relationship between temperature sum, precipitation sum, and saturation deficit sum and nitrogen uptake for each nitrogen and phosphorus fertilizer rate were determined. The effects of meteorological conditions on the uptake of nitrogen were influenced more by the fertilizer level than by the hybrids.

Jibrin *et al.* (2002) opined that phosphorus deficiency is the major constraint to maize (*Zea mays*) production in acidic soil of Heipang in Northern Guinea Savanna of Nigeria. The soil is high in sesquioxides and soluble aluminium and has high phosphate sorption capacity. To address this problem, a field trial was conducted between 1996-97 to assess the responses of six tropical cover crops (Glycine max, Chamaecrista rotundifolia, Lablab purpureus, Mucuna pruriens, Phaseolus vulgaris and Cajanus cajan) and maize to lime and applied rock phosphate and to evaluate the effect of these treatments on the performance and P nutrition of succeeding maize. Results of the trial showed that planting Chamaecrista rotundifolia, Lablab purpureus, Mucuna pruriens, and maize-C. rotundifolia intercrop reduced the leaf Al concentration of succeeding maize by more than 38%. Although none of the six cover crops significantly increased grain yields of succeeding maize, C. rotundifolia was the most consistent in improving maize performance while Glycine max produced the least performance. Concentration of Mn in the index leaves of maize was significantly higher on plots where G. max preceded maize, thus accounting for the poor performance of maize on these plots. Application of Sokoto phosphate rock at 30 kg ha^{-1} to cover crops produced very significant improvement in the yields of succeeding maize. While liming with 1.35 t CaO ha^{-1} in 1997 increased the soil pH value by 0.2 and significantly improved total P uptake by maize.

Purushotham *et al.* (2002) conducted a study in Tiptur, Karnataka, India, to investigate the response of fodder maize to different levels of NPK (100, 75 and 50% recommended dose of fertilizer (RDF)) and sulfur (0, 20, 40 and 60 kg sulfur/ha) under irrigation during late rabi seasons of 1994 and 1995. Most growth parameters, except leaf area and green fodder yield, were not significantly influenced by the different fertility levels and sulfur nutrition. The leaf area was significantly increased (11.1%) at 40 kg S/ha. It is suggested that the fertility level of 50% RDF - 75:37.5:25 kg NPK/ha is the optimum for fodder maize in late rabi season under irrigation.

Manoj-Kumar and Singh (2003) conducted a field experiment during the rainy season (*kharif*) of 2000 at SASRD, Medziphema, under rainfed condition of Nagaland, India to study the effect of nitrogen and phosphorus levels on yield and nutrient uptake of maize (Z. mays) cv. Vijay. The treatments comprised four nitrogen levels (N_0, N_{50}, N_{100} and N_{150}) and three phosphorus levels (P_0, P_{40} and P_{80}). The stover and grain yield increased significantly with the increasing level of nitrogen and phosphorus. The highest stover and grain yields were 64.92 and 30.0 q/ha, respectively, with the highest level of nitrogen and phosphorus (N_{150} and P_{80}) combination. Interaction among different rates of nitrogen and phosphorus did not show any significant effect on stover and grain yields. The nitrogen and phosphorus uptake by grain and straw increased significantly upto 150 and 80 kg/ha, respectively. The highest N uptake was 52.89 and 33.76 kg/ha in grain and straw, respectively. The highest phosphorus uptake by grain was 12.68 kg/ha and straw 20.77 kg/ha with N_{150} and P_{80} combination. The highest K uptake by straw and grain was 9.89 and 80.94 kg/ha, respectively, and it increased with increasing levels of nitrogen and phosphorus.

Singh *et al.* (2002) studied the growth responses of maize genotypes, i.e., VL90 and VL16 of low and VL89 and HIM129 of relatively high P requirements, to inoculation with a native consortium of arbuscular mycorrhizal (AM) studied in a sandy loam soil fertilized with single superphosphate (SSP) to provide 0 (P_0), 60 (P_1), 90 (P_2) and 120 (P_3) mg P kg^{-1} soil. AM colonization significantly increased vegetative plant growth after 45 days at P_0 and P_1 levels for genotype VL90 and VL16, at P_2 and P_3 levels for VL89 and P_0, P_1 and P_2 levels in HIM129. Except for VL89, a growth depression in roots and shoots of AM plants was observed at either P_2 or P_3 levels. This was most pronounced in VL90 and VL16. In contrast, in non-mycorrhizal plants no growth depression was observed; genotype VL90 at P_3 was an exception. Root and shoot P, and shoot Zn concentrations were significantly higher in AM compared with non-mycorrhizal plants, at various P levels. However, the pattern of phosphorus and zinc uptake in mycorrhizal and non-mycorrhizal shoots was genotype specific. Alkaline phosphatase (ALPase) activity of mycorrhizal and non-mycorrhizal roots was variable with respect to genotype and soil P level. In mycorrhizal roots ALPase activity was significantly higher at P_0 and P_1 levels in VL90, P_0, P_1, P_2 level in VL16, P_2 and P_3 levels in VL89 and at all P levels in genotype HIM129.

Stanchev (2001) investigated the effect of phosphorus and zinc fertilization on the accumulation of biomass of the maize hybrids P3978 (FAO310), Kneja 430 (FAO 430) and 4708 (FAO 650) grown monoculture and the removal of phosphorus with over ground povet of maize in a field fertilized trail without irrigation on calcareous chernozem in North-East Bulgaria. It was found that the contents of phosphorus increased and the biomass decreased from the high rates of P fertilization. The dry matter of maize hybrids increased, but the P contents decreased from the zinc fertilizer more clearly expressed for vegetative mass compared to the effect of maize. The formation of biomass is in direct dependence with the level of phosphorus and the applied zinc fertilizing as well as with the meteorological conditions during the vegetation of the maize hybrids. The hybrid P3978 (FAO310) was formed 10.3-16.6 t/ha biomass in the over ground part of the plants and removed 44.8-60.1 kg/ha P_2O_5 and hybrid 4708 (FAO680) was formed 7.7-19.68 t/ha biomass and 19.2-82.6 kg/ha P_2O_5 removed with it. It was found that the hybrid P3978 consumed 7.0-15.4 kg P_2O_5, Kneja 430-7.4-16.4 kg, and H708-5.5-16.7 kg per 1 t of grain and vegetative mass. With the aid of derived regression equations the removal of phosphorus along with the yields of organic mass of maize hybrid in Northwest Bulgaria. Values are suggested for the consumption of P, which may be applied in determined fertilization rates for yields of maize hybrids.

Leach and Hameleers (2001) grew forage maize (*Zea mays*) in areas where spring temperatures are low and accumulated heat is limited will be restricted in terms of maturity and thus nutritional value. A stagnant growth phase is commonly caused by low temperatures between germination and the five-leaf stage, which could be caused by reduced mineral availability. The effects on maize plant development and harvest characteristics of supplying phosphorus and zinc to young plants in a foliar spray were investigated. Three different application dates, between the four-leaf and the seven-leaf stage, were compared. Applying the phosphorus and zinc foliar spray at the four-leaf stage resulted in a significant ($P<0.05$) increase in starch content at harvest. Cob index (proportion of plant dry matter (DM) in the cob) was increased ($P<0.05$) by applying the nutrient spray at the four-, five- and seven-leaf stages. However, there was no effect on DM yield, suggesting some alteration in partitioning within the plant.

Sankhyan *et al.* (2001) conducted a study in an Alfisol at Palampur, Himachal Pradesh, India, during 1994 and 1995, to determine the effect of mulching with an organic waste from wild sage (Lantana camara), farmyard manure (FYM) and phosphorus on soil moisture and productivity of maize. Results showed that there was no significant effect of phosphorus levels on soil moisture content at 0-15, 15-30 and 30-45 cm depth in both years. Application of Lantana mulch improved the soil moisture content. Application of FYM increased the soil moisture content at 0-15 and 15-30 cm depths at flowering in 1994 and 1995, but there was no significant effect at 30-45 cm depth. There was a significant and consistent increase in the productivity of maize at each level of phosphorus over control during years. Lantana mulch increased dry matter production and grain and stover yields. The dry matter productivity and grain and stover yields recorded a significant increase with the application of 10 t FYM per ha over no FYM application. Interaction effect involving FYM and mulch on soil moisture at 0-15 and 15-30 cm depths was found significant in 1995, whereas, in the other depths and year, no significant effect was observed in the treatment

Ortas *et al.* (2001) investigated the effects of selected mycorrhizal inoculates on growth, zinc (Zn), and phosphorus (P) uptake of maize and green pepper in a Zn- and P-deficient calcareous soil from the Central Anatolia, Turkey. The soil was sterilized by autoclaving and plants were grown for 7 weeks in pots under greenhouse conditions with inoculation of two selected arbuscular mycorrhizal (AM) species (G. mosseae and G. etunicatum) at three rates of P (0, 25 and 125 mg P kg^{-1} soil) and two rates of Zn (0 and 5 mg Zn kg^{-1} soil). Without mycorrhizal inoculation, shoot and root dry matter production were severely affected by P and Zn deficiencies, and supply of adequate amounts of P and Zn significantly enhanced plant growth. When the soil was inoculated with mycorrhizal inoculates, the positive effects of P and Zn fertilization on plant growth remained less pronounced. In agreement with growth data, mycorrhizae inoculation enhanced P and Zn concentration of plants, especially under low supply of P and Zn. The results indicate that maize and green pepper [*Capsicum* sp.] are highly mycorrhizal-dependent plant species under both low P and Zn supply and mycorrhizae play an essential role in P and Zn nutrition of plants in P and Zn deficient soils.

Hussaini *et al* (2001) carried out a field study from 1996 to 1998 at the Sudan Savanna region of Nigeria to evaluate the effects of four levels of nitrogen (0, 60, 120 and 180 kg N/ha), three irrigation regimes based on irrigation water:cumulative pan evaporation ratios (IW:CPE) of 0.6, 0.8 and 1.0, and three phosphorus levels (0, 20 and 40 kg P/ha) on the growth and development of maize. Nitrogen fertilization significantly enhanced the growth of maize in terms of total dry matter, plant height, growth rate and leaf area index, while the effect of P was not so pronounced. Increasing frequency of irrigation resulted to a positive response in the growth and development of maize, with IW:CPE ratio of 1.0 outperforming the other irrigation levels.

Patel *et al.* (2000) conducted a field experiment to study the response of phosphorus (P) level on the growth and yield of maize in Gujarat, India, during the *kharif* seasons of 1995-97. Treatments comprised: 4 P levels (0, 20, 40 and 60 kg/ha). The highest plant height (161 cm) and dry matter production (3680 kg/ha) were observed upon treatment with 60 kg P/ha. The highest number of cobs per hectare (69 167) and test weight (195 g) were recorded upon treatment with 60 kg P/ha, which were at par with those obtained upon the 40 kg P/ha treatment. The highest net return (Rs. 9772/ha) was obtained upon treatment with 60 kg P/ha with a cost benefit ratio of 1:2.58, followed by treatment with 40 kg P/ha which recorded Rs. 8942/ha net return and 1:2.55 cost benefit ratio. Treatment with 60 kg P/ha recorded the highest yield (2453 kg/ha).

Nziguheba *et al.* (2002) conducted a field experiment on a P-fixing Acrisol in western Kenya to study the possibilities of replenishing soil P with seasonal additions of small rates of P fertilizers. Triple superphosphate was applied at 0, 10, 25, 50 and 150 kg P ha^{-1} for 5 consecutive maize growing seasons followed by 4 seasons of residual crops. Maize yields and soil P fractions were determined. Although maize responded to additions of 10 kg P ha^{-1} with a cumulative grain yield of 16.8 t ha^{-1}, at the end of the experiment, compared to 8.8 t ha^{-1} in the non-P fertilized plots, soil labile P did not increase correspondingly. Seasonal additions of 150 kg P ha^{-1} increased maize yields to a cumulative value of 39 t ha^{-1} at the end of the experiment, and increased all soil inorganic P fractions. At the third season of residual phase, treatment with a cumulative addition of 750 kg P ha^{-1} gave the highest yields compared to treatments in the same residual stage, but these yields were considered less than the maximum yield of the season. This indicates that the large build up of soil P was not available for crop uptake. The inorganic P fraction extracted by $NaHCO_3$ was the most affected by changes in management, increasing during the input phase and decreasing after interruption of P addition, for all P rates. The decrease in this pool during the residual phase could be explained by the maize uptake. This study showed that seasonal additions of 25 kg P ha^{-1} can increase maize yield with gradual replenishment of soil P.

Ling-Fan and Silberbush (2001) conducted an experiment to determine the efficiency of different forms of nitrogen-phosphorus-potassium (NPK) fertilizers applied to maize (*Zea mays*), either to the soil or to the leaves. Two sweet corn plants (cv. Jubilee) were grown in plastic bags with 10.5 kg silt loam desert soil (Typic Haplocalcid). Before planting, the soil was mixed with zero (control), half or full dose of 0.6 g N, 0.4 g P, and 0.3 g K per pot as mineral forms, or as the "Global-Green" (GG) foliar fertilizer. Three forms of foliar fertilization were applied once a week in equivalent concentrations of N, P, and K (0.12 g N, 0.08 g P, and 0.06 g K^{-1}): Mineral forms (NPK), GG, and "Fertilizers & Chemicals" foliar fertilizers; plain water acted as the control. The plants were harvested after 55 days. The roots were washed from the soil and length measured. The shoots were measured for leaf area, fresh and dry weight, and leaf contents of chlorophyll, N, P, and K. All indices increased in response to all forms of foliar fertilization (FF), but no significant difference was obtained between the different forms. Global-Green was less effective as a soil fertilizer (SF) than NPK. The effectiveness of FF appeared to be limited by the holding capacity of leaf surface area for the liquid fertilizer. It was concluded that FF may partially compensate for insufficient uptake by the roots, but requires sufficient leaf area to become effective.

2.2 Response of maize to sulphur fertilization

Khan *et al.* (2006) conducted a field experiment to assess the effect of different levels of sulfur (S) on yield and yield components of maize crop grown on silt loam soils at the Agriculture Research Station Baffa, district Mansehra. The soil contained 1.17% organic matter, 10% $CaCO_3$, and 39 mg SO_4-S kg^{-1}. Sulfur was applied at 0, 20, 40, 60, 80, 100, and 120 kg ha^{-1} as gypsum along with 120 kg N, 90 kg P_2O_5, and 60 kg K_2O ha^{-1} replicated thrice in RCB design. Soil samples at silking and harvesting stage from each treatment plot along with leaf samples were collected for the determination of S. Yield and yield components of maize were significantly ($p<0.05$) enhanced with the application of S compared with control.

Sulfur at 60 kg ha^{-1} produced the highest yield of fresh matter, dry matter, stover, 1000-grain and total grain, resulting in increases of 41, 55, 58, 5, and 43%, respectively. Application of S above 60 kg S ha^{-1} reduced yield and yield components, suggesting a classical yield response curve. The analysis of soil samples at silking and harvesting stage from each treatment plot revealed that soil SO4-S concentration increased significantly by S application reaching the level of 108.4 and 99.7 mg kg^{-1}, respectively, with 120 kg S ha^{-1}. Sulfur concentration of leaves was significantly increased with the application of S compared with the control. Application of sulfur at 60 kg ha^{-1} produced leaf S concentrations of 0.46%, which is less than the critical level of 0.5%, whereas higher treatments increased S concentration ranging from 0.67 to 0.94%, which exceeded the value considered as high (0.5%) and excessive (0.8%). Elevated tissue sulfate concentrations induced by treatments greater than 60 kg ha^{-1} corroborate with the corresponding yield decreases of maize. Maize growers of the area may add S up to 60 kg ha^{-1} to obtain maximum yield.

Mehta *et al.* (2005) conducted a field experiment during the rainy (*kharif*) seasons of 1999 and 2000, on clay loam soil, in Udaipur, Rajasthan, India, to study the effects of sulfur (0, 30 and 60 kg/ha), phosphorus (20, 40 and 60 kg/ha) and farmyard manure (FYM) (0 and 10 t/ha) on the productivity of maize. Data were recorded for cobs per plant, rows per cob, cob weight, grain weight per cob, shelling percentage, seed index, seed and stover yields, and N, P, S and Fe uptake. All parameters increased with increasing levels of sulfur, phosphorus and FYM. However, no significant differences were observed between the two higher rates of phosphorus.

Fonseca *et al.* (2005) carried out an experiment to study the effects of maize to irrigation with secondary-treated sewage effluent (STSE) on soil pH, electrical conductivity (EC), and on the available soil concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), aluminium (Al), sulfur (S), boron (B), and of heavy metals and to investigate the plant element accumulation, except for Al. The treatments consisted of mineral fertilization and irrigation with the STSE. After 58 days, maize plants were harvested, and soil and plant were analysed. The STSE effectively reduced the mineral nitrogen fertilizer soil-acidifying effect, induced increases in the EC, and in the base saturation, and did not significantly alter the available concentrations of S, B, and heavy metals. The STSE irrigation did not affect the shoot S, B, copper (Cu), iron (Fe), and manganese (Mn) contents in plants properly fertilized, but it induced a decrease in shoot zinc (Zn) content. Sodium was the most affected element by the STSE irrigation.

Cui *et al.* (2004) conducted a pot experiment to study the influence of elemental sulfur (S) on solubility of soil Pb, Zn and Cd and uptake by maize (*Zea mays* L.). Two rates of elemental sulfur (S) applied at 0 (S_0) and 200 (S_{200}) mmol kg^{-1} soil with three rates of each heavy metal at Pb, 0 (Pb_0), 200 (Pb_{200}), 400 (Pb_{400}) mg kg^{-1} soil, Zn, 0 (Zn_0), 100 (Zn_{100}), 200 (Zn_{200}) mg kg^{-1} soil and Cd, 0 (Cd_0), 50 (Cd_{50}), 100 (Cd_{100}) mg kg^{-1} soil, respectively. The result showed that with S application at 200 mmol S kg^{-1}, soil pH decreased about 0.3 units and the solubility of the Zn and Cd was significantly increased, but the solubility of Pb had no significant influence. The concentration of Pb, Zn and Cd in maize shoots and roots were increased with increasing rates of heavy metals. However, the concentration of Zn and Cd in shoots and roots were higher with application of S rather than without S but no significant difference was found for Pb. The highest concentration of Zn in the shoots was 2.3 times higher with application of S rather than without at the same rate of Zn, 200 mg kg-1. Plant biomass was also significantly affected by the application of S and of heavy metals. With heavy metal addition, the shoot and root biomass were decreased with the rates of those of heavy metals increased either with or without application of S. However, the shoot biomass was significantly decreased with S application at the same rate of heavy metals except that with Zn addition. The removal of Cd and Pb by maize uptake and accumulation with application of S had no significant increase compared to that without, but the removal of Zn by maize uptake from the soil increased by application of S, 90.9 micro g plant^{-1} contrasts to 25.7 micro g plant^{-1} at Zn 200 within a growth period of only 40 days.

Pandey *et al.* (2002) studied the effects of sulfur (0, 10, 20, and 30 mg/kg soil) on dry matter yield and plant nutrition in maize (hybrid Deccan 103) grown in pots containing soil types (25 soil types categorized as Inceptisol, Alfisol, Mollisol, and Vertisol) of various physicochemical properties and available sulfur content, which were collected from India (Uttar Pradesh, Bihar, Madhya Pradesh, Andhra Pradesh, Karnataka, New Delhi, and Haryana). Sulfur application up to 20 mg/kg significantly increased dry matter yield, sulfur content, and sulfur uptake. In general, the response to applied sulfur was greater in soils with low content of available sulfur (<10 mg/kg soil) than in soils with high content of available sulfur (>10 mg/kg).

Majumdar *et al.* (2002) conducted a field experiment in Umiam, Meghalaya, India, for two consecutive years (1999-2000) with 3 levels of N (0, 50 and 100 kg/ha). 2 levels of S (0 and 20 kg/ha), and 2 levels of pig manure (O and 5 t/ha). The increasing levels of N, S and pig manure were found to increase the yield, nitrogen and sulfur uptake and crude protein content of maize and residual mustard crop significantly. The oil content of mustard decreased with N application but increased with S and pig manure application. The post harvest contents of available S, N and inorganic, N-fractions in soil significantly increased with N, S and pig manure application. The interaction effects of nitrogen and sulfur and nitrogen and pig manure significantly influenced the yields and nutrient uptake of both maize and mustard crops. Nitrogen use efficiency estimated as agronomic efficiency, physiological efficiency and also apparent N recovery were found to be higher at 50 kg N in comparison to 100 kg N/ha for both the crops. Application of 100 kg N, 20 kg S+5 t pig manure/ha was found suitable to get maximum grain yields and better quality for both the crops.

Sankaran *et al.* (2002) carried out an investigation to study the available S status of some soils of Coimbatore district, Tamil Nadu, India, and to evaluate the direct and residual effect of S application on maize-green gram cropping system. Sulfur deficiency was greater in red soils (Udic Haplustalf) than in alluvial soils (Fluventic Haplustalf). A positive correlation was observed between available S and organic carbon. Results of field experiments conducted in two locations showed that maize responded to direct application of S up to 45 kg ha^{-1} as judged by increased yield of grain and straw, S uptake and available S status. A residual effect of S on succeeding green gram was also observed. Based on S use efficiency and value cost ratio, 30 kg S ha^{-1} was found to be optimum for the maize-green gram cropping system.

Dhananjaya and Basavaraj (2002) conducted a field experiment in Dharwad, Karnataka, India, during the summer season of 1997-98 in an Alfisol to study the effect of different levels of sulfur application on transformation and uptake by maize cv. 'Deccon-103'. Sulfur was applied at four levels viz., 0, 15, 30 and 45 kg/ha through single superphosphate. Results showed that maize decreased the contents of soil sulfur fractions originally present in soil compared to 0 kg S/ha. However the values of different fractions of sulfur in soil increased with increased level of sulfur. A close relationship existed between different fractions of sulfur and plant uptake of S and crop yield. Organic S content had a significant positive relation with total water soluble S and available sulfur. The grain and stover yields of maize increased significantly with the application of S at 15, 30 or 45 kg S/ha.

N, P, and S uptake increased due to the application of sulfur. The N: S and P: S ratio decreased significantly due to S application.

Patel *et al.* (2002) has been reported, the deficiency of S in Gujarat soils to the extent of 40%. As the deficiencies are mostly observed in middle Gujarat and Saurashtra regions, a delineation programme under TSI/FAI/IFA sponsored project was carried out in selected representative blocks of these regions. In all 237, 210 and 240 surface soil samples were collected from Dhari, Lunawada and Devgadhbaria blocks, respectively. The overall mean of S was 19.2, 13.3 and 15.2 ppm for corresponding sites. Field experiments were conducted on farmer's fields for groundnut-wheat sequence on clay loam calcareous (Lythic Ustorthents) soils in Amreli district (Saurashtra region) at Dhargani; and on sandy loam (Fluventic: Ustochrepts) soils at Dhesia in Panchmahal district; maize and gram in sequence on silty loam (Fluventic Ustochrepts) soil at Dudhia in Dahod district (Middle Gujarat) in order to study the crop response to applied sulfur (S) under different levels to the first crop and its residual effects on succeeding crop. The soils were deficient to marginal in S status and pH was in alkaline range at Dhargani & Dhesia while it was nearly neutral at Dudhia. The results of field experiments indicated that the S application increased the yields of groundnut at both the sites and of maize at Dudhia. At Dhargani, maximum yield of groundnut due to S application was found under the medium level i.e. 30 kg/ha, while at Dhesia the maximum yield was recorded under maximum (i.e. 45 kg S/ha) level of S application; but this improvement was at par with medium level of S application (30 kg/ha). The residual effect of S applied to the first crop at both the sites was found significantly superior in increasing wheat grain and straw yields. The pattern of increase in yield was reflected in the utilization of S also. The overall results indicated that the S application @ 30 kg/ha was beneficial and economically superior over other levels as well. Thus, the results revealed the importance of S in balanced fertilization for higher crop yields.

Liu *et al.* (2002) conducted a field experiment with maize cv. DR3112 in 1995 in the experimental farm of Shandong Agricultural University, China. Sulfur fertilizer (as base fertilizer) was applied at 0 (control), 36.3 (S_1) and 413.85 kg/ha (S_2) in the $(NH_4)_2SO_4$ form. Sulfur application (SA) increased grain yield, cob length, rows/cob and kernels/cob significantly, but had no obvious effects on 1000-kernel weight. Absorption amounts in single plant of N, P, K, Mn, Zn and Mg ranked as $S_2 > S_1 >$control. The pH values at the soil layers (SLs) of 0-20, 21-40, and 41-60 cm decreased significantly in the SA treatments. The pH value at each SL ranked in control $> S_1 > S_2$. Total N and available K contents at the SL of 0-60 cm and available P content at 0-20 cm increased in SA treatments, but available P content at 21-40 cm showed insignificant change and a trend at 41-60 cm for a significant increase.

Liu *et al.* (2001) found in a field test in 1995, sulfur applications of 36.3 and 413.85 kg/ha resulted in maize yields of 10639.5 and 11322 kg/ha, respectively. These yields were 8.73 and 15.71% higher than control plots, respectively. Sulfur application increased ear length, rows/ear, grains/row and grains/ear, but not grain weight. Dry matter, leaf area assimilation (NAR), uptake of N, P, K, Mn, and Zn, as well as Fe, Mn, and Zn levels in leaves increased with increasing level of sulfur application.

Ramirez *et al.* (1999) in greenhouse experiments studied the effects of ammonium thiosulphate (ATS) on maize dry matter and nitrogen (N) and sulfur (S) uptake in a sodic soil. In a first experiment, ATS was mixed with the soil at S rates of 0, 30, 50, 70 and 100 mg/kg soil. In a second experiment, ATS was band-applied to the soil at rates of 0, 140, 270 and 400 mg/kg soil. In both experiments, dry matter yields were significantly increased with the increment of the ATS dose applied to the soil. Banded ATS produced higher maize dry matter, N and S uptake than ATS mixed with the soil.

Gordon *et al.* (1992) conducted two trials in 1990 in the zone of Azuero (Panama) to observe the response of maize to the residual effect of sulfur (CaSO4, gypsum) under two application methods. In 1989, sulfur was broadcasted at rates of 0, 20, 40 and 80 kg/ha or handspiked at rates of 0, 20 and 40 kg/ha. During the second cycle (1990), only 100 kg N/ha was applied to the plots to determine the residual effect of the treatments. There was a lineal response for the two gypsum application methods in the first cycle, but there was no interaction among these two independent variables. The fact that one of the highest yields was obtained with 20 kg S/ha shows that a low rate of this element is enough to have significant responses. The residual effect of sulfur application (1990) was highly significant, resulting in yield increments ranging from 0.483 to 1.682 t/ha. The economic analysis of the two cycles (1989-90) showed that the sulfur application was profitable with respect to 0 rates, given the low cost of the agricultural gypsum.

Singh and Chhibba (1991) reported that maize (*Zea mays*) and wheat (*Triticum aestivum*) grown under greenhouse conditions on a S-deficient Typic Ustipsamment responded significantly to S applied through ammonium sulfate, superphosphate, gypsum, elemental S and pyrites irrespective of the carriers. For maize, ammonium sulfate, superphosphate, gypsum and elemental S proved equally efficient. For wheat on the other hand, ammonium sulfur was the most efficient. Superphosphate and gypsum were significantly better than elemental S and pyrite.

Sachdev and Deb (1990) found in trials in 1986-88 with 2 cycles of a *Brassica juncea* /*Vigna aureus* [*V. radiata*]/maize rotation, *B. juncea* was given 0, 30 or 60 kg N and 0, 20 or 40 kg S/ha using ^{15}N- and ^{35}S-labelled fertilizers. Effects of the treatments on N and S uptake and utilization in the cropping sequence were studied. Both N and S showed a synergistic effect on DM yield and N and S uptake in *B. juncea*. The utilization of fertilizer N and S was 53-69 and 20-39%, respectively, in *B. juncea*. Application of 20 kg S increased the seed oil content from 38.2-38.5% with no S to 39.3-39.5% and oil yield by 10.6% (76 kg/ha). Uptake of residual fertilizer N and S was only 1-3% in *V. radiata* and maize.

2.3 Response of maize to the combined application of P and S:

Setia and Sharma (2005) found that the available, water soluble and heat soluble sulfur (S) contents over a profile depth of up to 120 cm were determined in a long-term experiment which was continuously cropped with maize [*Zea mays*]-wheat [*Triticum aestivum*] sequence at the Punjab Agricultural University Farm in Ludhiana (Punjab, India). The minimum amount of S was found in water soluble form. All the forms of S decreased with increasing soil depth but this effect was more noticeable up to 45-60 cm soil depth. The increasing level of N, P and K affected depth-wise distribution of S. The content of all the forms of S increased with application of 40 kg P_2O_5 ha-1 but the trend reversed with the application of 80 kg P_2O_5 ha^{-1}, irrespective of N levels. Application of 40 kg K_2O ha^{-1} at all the levels of N and P resulted in a decline in all the forms of S. The accumulation of sulfur was lower in the NPK treated plots than N- and NP-treated plots. The amount of water soluble S in lower soil depth was found to be very low. Regression equations were used to predict S uptake by wheat using S status in different soil layers as independent variables. Multiple regression analysis indicated that the coefficient of determination (R_2) value between S uptake and available S improved significantly when its status up to 60-90 cm soil depth was included. Heat and water soluble S contributed significantly towards S uptake by wheat when accumulation of forms of S in the soil profile up to depth of 60-90 cm included in the regression analysis.

Yadav and Souza (1992) conducted a pot experiment in a greenhouse, maize was given equivalent to 0, 60 or 120 kg P_2O_5/ha as ammonium polyphosphate (APP) or diammonium orthophosphate (DAP) and 0, 5 or 10 kg Zn/ha as zinc sulphate and

0, 10 or 20 kg Fe as iron sulphate. After maize harvest, blackgram (*Phaseolus mungo* [*Vigna mungo*]) was sown in the same pots. P, Zn and Fe applications (and their residual effects) increased plant DM and uptakes of the 3 elements in both species. Interaction between P source and Zn and Fe was either slight (maize) or inconsistent (blackgram).

Debreczeni and Berecz (2000) reported that the nutrient responses of eight different maize hybrids differing in the duration of the growth period (FAO 200-430) were studied in field fertilizer trials conducted in four different agro-ecological regions of Hungary. Four treatments were applied: (1) minimum NPK dose, (2) NPK dose corresponding to the nutrient requirements of maize, (3) NPK dose exceeding the nutrient requirements of maize, (4) farmyard manure (FYM). The NPK contents of the grains were measured in addition to the grain yields. In most cases, nutrient supply exceeding the demand of the maize plants did not result in significantly higher grain, nitrogen, phosphorus or potassium yields at any of the sites. Compared with the minimum mineral fertilizer dose, FYM did not result in higher grain, nitrogen, phosphorus or potassium yields; in fact, these parameters were significantly lower in some cases. Considerable site and cultivar differences could be detected in the experimental parameters.

Dilip-Singh and Singh (2000) conducted an experiment at Udaipur during the summer and rainy seasons of 1995-96 to study the response of groundnut (*Arachis hypogaea*) and succeeding maize (*Zea mays*) to sulphur and phosphorus fertilization. The pooled data revealed that summer groundnut fertilized with 60 kg S/ha gave significantly higher pod yield (2.84 t/ha), grain yield (2.74 t/ha) of succeeding maize crop and net returns (Rs 41 400) over 30 and 0 kg S/ha. Similarly, phosphorus application up to 50 kg/ha recorded significantly higher yield (2.84 t/ha) and net returns (Rs 41 600/ha) over no P application. But its residual effect did not influence production of succeeding maize crop.

Jena *et al.* (2004) conducted a field experiment in Kandhamal district (Orissa, India) during *kharif* 1997 and *rabi* 1997-98 with maize-mustard cropping sequence grown on moderately acidic sandy loam soil (Typic Haplaquept) to evaluate the efficiency of Jhamarkota phosphate rock (JPR) compacted with monoammonium phosphate (MAP), MAP+Sulfur (S) and single superphosphate (SSP) along with granular MAP and granular SSP. The highest grain and stover yields of maize were recorded in granular MAP treatment closely followed by compacted fertilizer treatments. However, in the mustard crop, MAP+S and SSP were compacted sources out yielded water soluble P sources. Considering both the crops in sequence, MAP+S and SSP compacted P sources were found to give higher crop yields and better agronomic efficiency compared to other P sources. Both compacted and water soluble P sources significantly influenced the P, S and Ca uptake by crops over lone phosphate rock sources. The apparent phosphorus recovery from granular MAP was highest followed by granular SSP and compacted P sources with SSP, MAP+S and MAP.

Alvarez *et al.* (1987) reported that effects of 0 and 100 kg kg N/ha applied as KNO_3 at the 4-leaf state were studied on maize cv. Dekalb 4F 34. N treatment had no effect on shoot total S and P contents. Between the end of pollination and the final harvest there was an increase in mature grain S content in N-treated plants equivalent to 44% more than that in controls. The increased demand for S during grain development was apparently provided by remobilization of sugar from the leaves. The N: S ratios in mature shoots were 16.0 and 11.4 for N-treated and control plants; respectively. P distribution was similar to that of S. N treatment had no effect on total biomass accumulation. The N: P ratios in mature shoots were 4.9 and 3.3 in treated and control plants, respectively.

Lopez *et al.* (1991) reported that response of maize (*Zea mays*) to PHS (a biofertilizer obtained by the fusion of rock phosphate with elemental S followed by inoculation with Thiobacillus), layer 2 Monte Fresco rock phosphate (MF_2), and MF_2 + S (added in the same proportion as in PHS) was evaluated in the greenhouse against triple superphosphate (TS). Response was in the following order: TS > MF_2 > MF_2 + S > PHS. Yields increased linearly with increasing rates of TS and MF_2 (100 to 400 ppm P), but there were no significant differences between the S fertilizers at the higher rates.

Ramirez (1980) stated that step-wise multiple regression was used to analyse data from 28 experiments in Venezuela in which the leaf opposite and below the ear of maize was harvested at silking from plants given 0-150 kg N, 0-100 kg P_2O_5 and 0-100 kg K_2O/ha. Linear and positive effects were found for N, P, Ca and Mg concentrations. Optimum levels of various elements in leaves were calculated and standard values for a yield of 7 t/ha. Optimum and standard levels were 2.6 and 3.5%, respectively for N, 0.2 and 0.4% for P, 0.25 and 0.50% for Ca, 1.3 and 2.0% for K and 0.25 and 0.5% for Mg.

Talukder and Islam (1982) reported that during the *kharif* (monsoon) season of 1981 at 4 sites in Bangladesh, maize was grown with 0- 120 kg P_2O_5 and 0-50 kg S plus basal applications of 160 kg N + 60 kg K_2O/ha. Grain yield increased with increasing P and S rates at all sites from 0.68-2.89 t/ha and with no fertilizer to 3.71-5.79 t/ha with the highest rates of P and S.

Pierre *et al.* (1990) reported that in a field trial at Luperon in 1984-89, the effects of 40 kg N/ha, 0, 12, 20 and 40 kg P/ha and 0 and 43 kg S/ha on yields of maize cv. *Frances Largo* under no tillage and conventional tillage systems were evaluated. Limited N supply affected the response to P and S under no tillage. Both P and S increased maize yields and root and stalk loading. Sulphur volatilization due to burning in conventional tillage was important as the S response under no tillage was minimal.

Raun and Barreto (1991) reported that maize grain yields were increased by P and S in both the residual and treated cycles. In the treated cycles, yields when no P was applied were 4.95, 5.75 and 5.95 t/ha, at 0, 57 and 114 kg S/ha, respectively; when 22 kg P/ha was applied with 100 kg N/ha, yields were 5.38, 6.38 and 5.48 t/ha at the same S rates. Over the 4-cycle, yields were highest with 100, 22 and 57 kg/ha of N, P and S, respectively.

Sinha *et al.* (1995) conducted a field experiment at Dholi, Bihar on P and S deficient calciorthent (12.8 kg S/ha and 15.6 kg P_2O_2/ha) during the winter season of maize cv. *Lakshmi* was given 0-80 kg S/ha as ammonium sulphate and 0-120 kg P_2O_5/ha as triple super phosphate. Application of P or S (except at the highest rates) increased chlorophyll content in foliage, which was maximized when both elements were applied together. Grain and stover yields also increased with P and S applications. The highest grain yield of 7.64 t/ha was obtained with 60 kg P_2O_5 + 40 kg S.

Chapter 3
Materials and Methods

Chapter 3

MATERIALS AND METHODS

The present piece of research work was carried out at Sher-e-Bangla Agricultural University Farm, Dhaka during the *rabi* season of 2006-2007 to study the response of maize to phosphorus and sulphur fertilization. Details of the materials and methodology are presented in this chapter.

Description of the experimental site

3.1 Location

The experimental field is located at $23^{0}77'$ N latitude and $90^{0}3'$ E longitude with an elevation of 1.0 meter above sea level (Fig. 1).

3.2 Soil

The soil of the experimental field belongs to the Tejgoan series of the Madhupur Tract (Agro Ecological Zone AEZ – 28). The General Soil Type at the experimental field is Deep Red Brown Terrace Soil. Topsoil is silty clay loam in texture. Organic matter content is very low (1.34 %) and soil pH is 4.8. The land is above flood level and well drained. The initial morphological, physical and chemical characteristics of soil are presented in Table 1 and 2.

3.3 Climate

The annual precipitation of the site is 2152mm and potential evapotranspiration is 1297mm. 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 71.52 % to 81.2 5%.

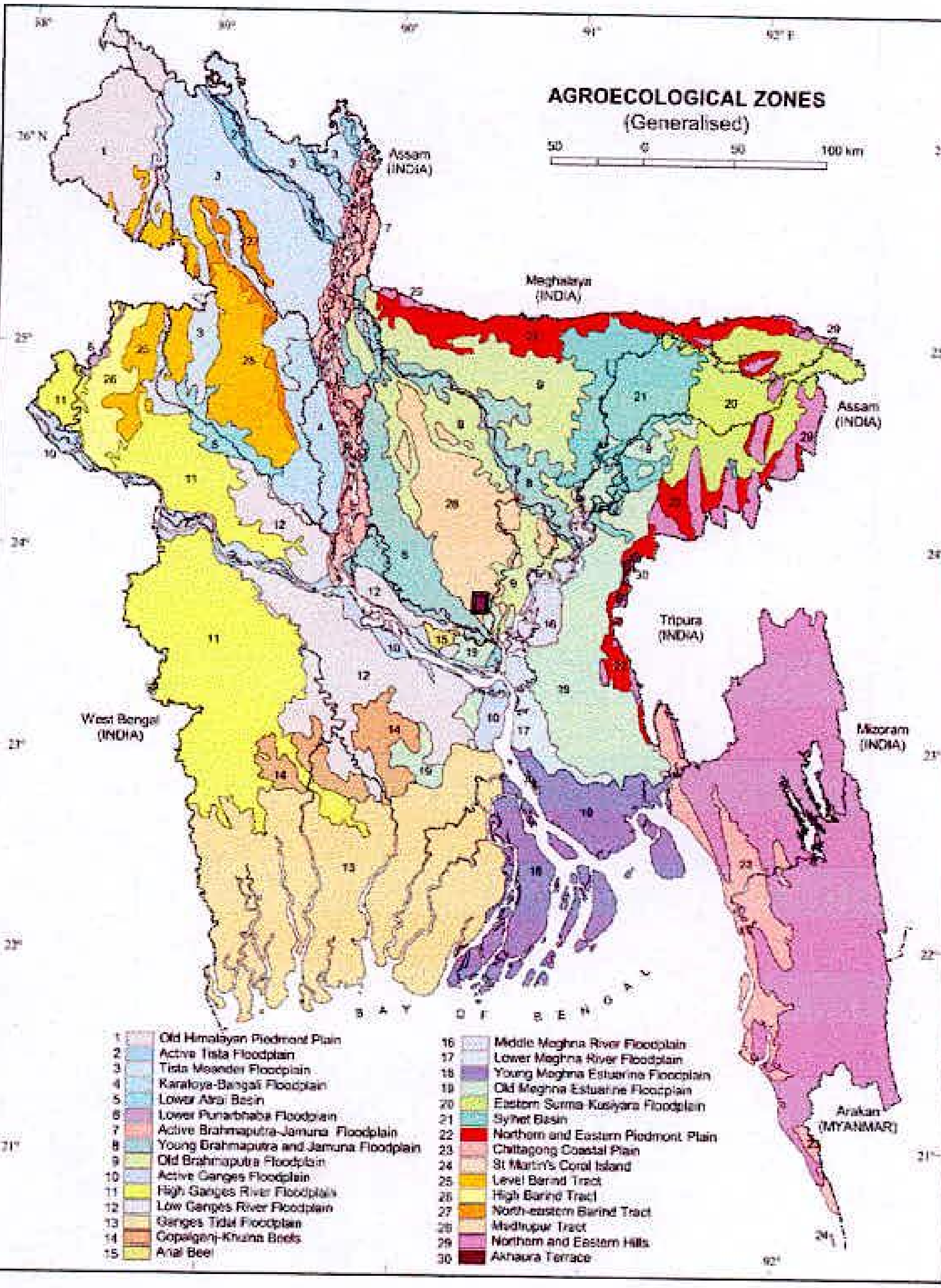

Fig.1. Map showing the experimental sites under study

▲ = **Experimental plot**

Fig. 2. Dhaka based map showing the experimental sites under study

Table 1. Morphological characteristics of experimental field.

Morphological Features	Characteristics
Location	Sher-e Bangla Agril. University Farm, Dhaka
AEZ No. and name	AEZ-28, Modhupur 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 2. Physical and chemical properties of the experimental soil.

Soil properties	Value
A. Physical properties	
1. Particle size analysis of soil.	
% Sand	23.6
% Silt	45
% Clay	31.4
2. Soil texture	Silty clay loam
B. Chemical properties	
1. Soil pH	4.8
2. Organic carbon (%)	0.84
3. Organic matter (%)	1.34
4. Total N (%)	0.0725
5. C : N ratio	9.75 : 1
6. Available P (%)	0.0029
7.Exchangeable K (me/100g soil)	0.18
8. Available S (%)	0.0014

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 .The monthly average temperature, humidity, bright sunshine, solar radiation, precipitation and potential evapotranspiration pattern of the site during the experimental work are presented in appendix -I.

3.4 Experimental treatments

The levels of phosphorus and sulphur used in the experimental treatments were as follows:

A. Phosphorus levels 4 (Kg P/ ha)

i) $P_O = 0$

ii) $P_1 = 35$

iii) $P_2 = 50$

iv) $P_3 = 65$

B. Sulphur levels 4 (Kg S/ ha)

i) $S_0 = 0$

ii) $S_1 = 25$

iii) $S_2 = 40$

iv) $S_3 = 55$

The treatment combinations for the experiment are given in Table 3

Table 3. The treatment combinations of phosphorus and sulphur fertilizers used in the experiment

Treatments	Combination of P and S	
	P (kg/ ha)	S (kg / ha)
$T_1 (P_0S_0)$	0	0
$T_2 (P_0S_1)$	0	25
$T_3 (P_0S_2)$	0	40
$T_4 (P_0S_3)$	0	55
$T_5 (P_1S_0)$	35	0
$T_6 (P_1S_1)$	35	25
$T_7 (P_1S_2)$	35	40
$T_8 (P_1S_3)$	35	55
$T_9 (P_2S_0)$	50	0
$T_{10} (P_2S_1)$	50	25
$T_{11} (P_2S_2)$	50	40
$T_{12} (P_2S_3)$	50	55
$T_{13} (P_3S_0)$	65	0
$T_{14} (P_3S_1)$	65	25
$T_{15} (P_3S_2)$	65	40
$T_{16} (P_3S_3)$	65	55

3.5 Crop

BARI MAIZE-5, a high yielding cultivar of maize was used as test crop in the experiment. Seeds were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur,Gazipur.

3.6 Design of the experiment and layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The whole experiment area was first divided into three blocks. Each block was later divided into sixteen plots. The size of each unit plot was 3m x 3m. Total number of unit plots was 48. The individual plots and the blocks were separated for irrigation and drainage by 1.5m and 2.0m channels, respectively. The layout of the experiment is shown in Fig.2.

3.7 Collection of initial soil sample

Initial soil samples were collected before land preparation from 0-15 cm soil depth. The samples were drawn by means of an auger from different location covering the whole experimental plot and mixed thoroughly to make a composite sample. After collection of soil samples, the plant roots, leaves etc. were picked up and removed. Then the samples were air dried and sieved through a 10-mesh sieve and stored in a clean plastic container for physical and chemical analysis.

3.8 Land preparation

The experimental land was opened by power tiller driven rotovalor on 26 October, 2006. The land was prepared by repeated plowing until the soil achieved a good tilth and was ready for sowing. Weeds and stubbles were removed and the plots were leveled by small ladder and the experiment filed was partitioned into unit plots in accordance with the experimental design mentioned in the section 3.6.

3.9 Fertilizer application

The required amounts of phosphorus and sulphur fertilizers were applied as per treatment combinations. Basal dose of N, K, Zn and B fertilizers were applied according to the fertilizers recommendation guide (BARC, 2005). Full doses of P (triple super phosphate) and S (gypsum) and one –third of the urea and the whole

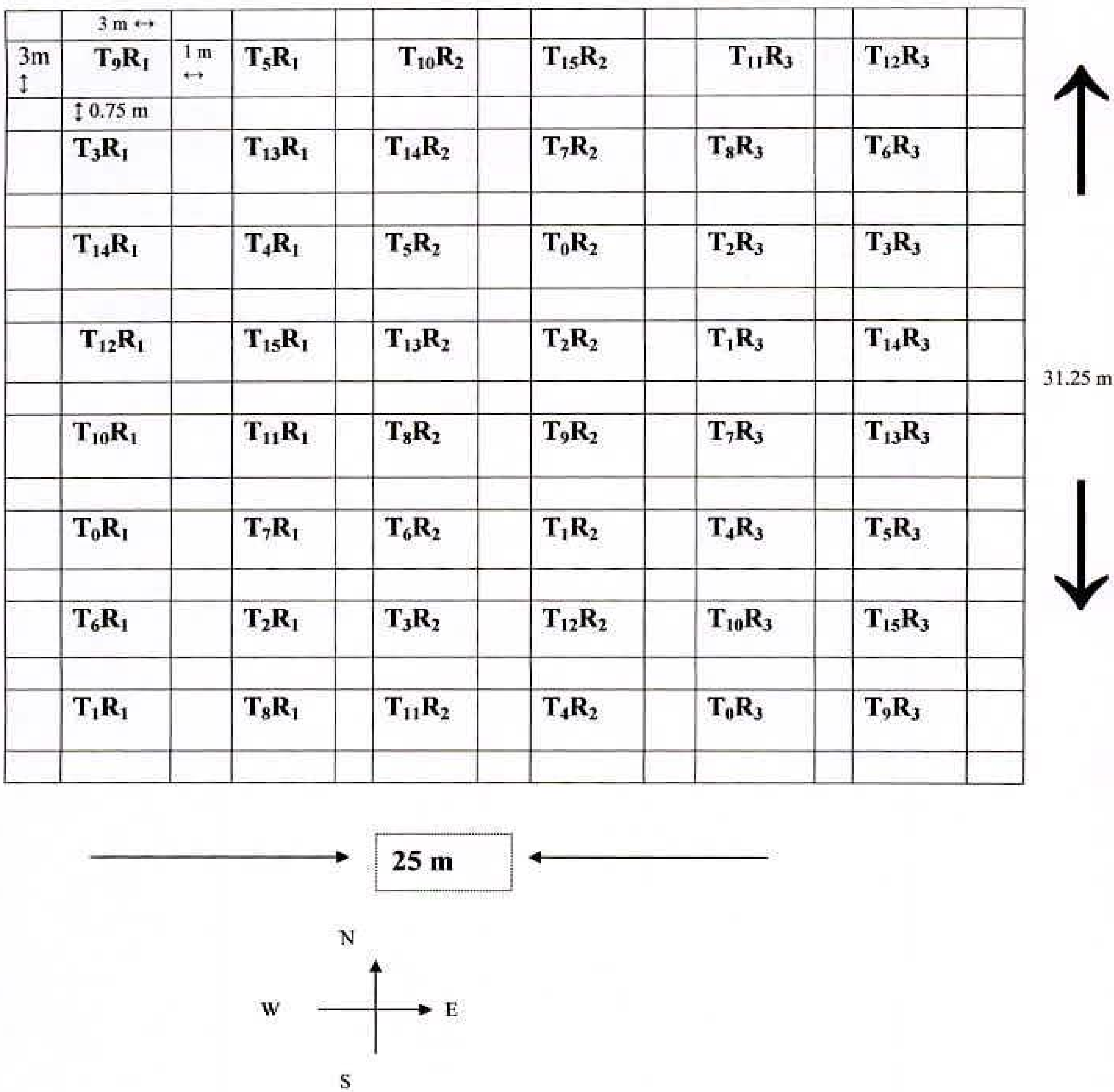

Fig. 3 Layout of the experimental plot.

required amounts of K, Zn and B fertilizers were applied at the time of final land preparation. The remaining urea was applied in two equal splits on 30 and 60 days after sowing (DAS).

3.10 Sowing of seeds

Seeds were sown on 27 October, 2006 in lines following the recommended line to line distance of 75 cm and plant to plant distance of 20 cm.

3.11 Gap filling

The seedlings of the crop emerged out within 6-8 DAS. Necessary gap filling was done at 12 DAS.

3.12 Weeding and thinning

Weeding was done three times, at 30, 45 and 70 DAS. Thinning was done after 25 DAS. One healthy plant was retained per hills and the other plant was removed.

3.13 Earthing up

Earthing up was done by spade at 45 DAS to prevent lodging of plants.

3.14 Irrigation and drainage

The plot was irrigated two times during the growing period of crop. Irrigation was applied first after 40 days and second after 70 DAS. Drainage was done when necessary by using drainage channels.

3.15 Insect and diseases control

There was no major incidence of insects or diseases. So, no pest control measure was adopted in the experiment. The experimental crop was grown with proper care and agronomic management to ensure satisfactory crop growth and development.

3.16 Plant protection

The damage of maize crops by jackals at booting and young cob stage was a big problem in the experimental area. Another greater problem in this locality was the damage of mature grains at the full mature cob stage by parakeets. Therefore necessary measures were taken to protect the crop from the probable damage by parakeets, jackals and birds.

3.17 Sample plants marking

For collecting data on plant characters and yield and yield components, five plants were randomly selected and marked with bamboo sticks in each plot.

3.18 Harvesting and processing

The experimental crop was harvested plot wise at full maturity on 17April 2007. The sample plants were harvested separately for recording data on plant characters and yield and yield components. The harvested crop of each plot was bundled separately, tagged and taken to threshing floor. These were dried in bright sunshine, shelled and the grains were cleaned properly. Grains and stovers were sun dried thoroughly before their weights were recorded. Grain and stover yields were then converted into t/ ha.

3.19 Collection of experimental data

Data on the following plant characters and yield and yield components were collected from the sample plants of each plot.

(1) Plant height (cm)

(2) Number of cobs/plant

(3) Cob length (cm)

(4) Circumference of cob (cm)

(5) Number of grains /cob

(6) Weight of 1000-grain (g)

(7) Shelling percentage

(8) Grain yield (t/ha)

(10) Stover yield (t/ha)

3.20 Details procedures of recording of data

A brief out line of the data recording procedure is given below:

(1) Plants height at harvest (cm)

Plant height was measured from the base of the plants up to the tip of the tallest leaf.

(2) Number of cobs plants

Number of total cobs were counted from the sample plants and then averaged and recorded.

(3) Cob length (cm)

Cob length was recorded from the base to the apex of each cob and averaged

(4) Circumference of cob (cm)

Circumference of cob was recorded at the lower and upper ends, and the middle of the cob and then averaged and recorded.

(5) Number of grains/cob

Total number of grains/cob from the sample plants were counted averaged and recorded.

(6) Weight of 1000-grain (g)

One thousand clean fried grains were counted form the seed obtained from sample plants of each plot and weighed by using an electrical balance and recorded.

(7) Shelling Percentage

It denotes the ratio of total grain weight/cob and total cob weight and was calculated with the following formula:

$$\text{Shelling percentage} = \frac{\text{Total grain weight/cob (g)}}{\text{Total cob weight (g)}} \times 100$$

(8) Grain yield (t/ha)

Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of five sample plants were added to the respective plot yield to record the final grain yield /plot (kg). The grain yield was converted to ton/ha.

(9) Stover yield (t/ha)

Stover obtained from each unit plot including the stover of the sample plants of respective unit plot were dried in sun and weighed to record the final stover yield /plot (kg) and finally converted to ton/ha.

3.21 Chemical analysis of soil samples

Soil samples collected before starting the experiment (Initial soil samples) and after harvest of the crop, were analyzed for both physical and chemical properties. The analysis was done at the Laboratory of the Department of Soil, Water and Environment, University of Dhaka. The properties studied included soil texture, pH, organic matter, total N, available P, exchangeable K and available S. The physical and chemical properties of the initial soils have been presented in Table 1 and 2. The soil was analyzed following standard methods:

Particle-size analysis: Particle size analysis of soil was done by Hydrometer method (Bouyoucos, 1926) and the textural class was determined by plotting the value of % sand, % silt and % clay on the "Marshall' s Textural Triangular Coordinate".

Soil pH: pH was measured with the help of a glass electrode pH meter using soil water suspension of 1:2.5 ratio as described by Jackson (1962).

Organic carbon (%): Organic carbon in soil was determined by Walkley and Black's (1934) wet oxidation method.

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

Soil organic matter (%): Soil organic matter content was calculated by multiplying the percent value of organic carbon with the Van Bemmelen factor, 1.724 as described by Piper (1942).

% organic matter = % organic carbon × 1.724

Total nitrogen (%): Total nitrogen of soil was determined by micro Kjeldahl method, where soil was digested with 30% H_2O_2, and conc. H_2SO_4 and catalyst mixture (K_2SO_4:$CuSo_4.5H_2O$: Se powder in the ratio of 100:10:1). Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titrations of the distillate trapped in H_3BO_3 with 0.01 N H_2SO_4 (Bremner and Mulvaney, 1982).

Available Phosphorus (ppm): Available P was extracted from soil by shaking with 0.5 M $NaHCO_3$ solution of pH 8.5 (Olsen *et al.* 1954). The Phosphorus in the extract was then determined by developing blue colour using ascorbic acid reduction of phosphomolybdate complex. The absorbance of the molybdophosphate blue colour was measured at 660 nm wave length by spectrophotometer and available P was calculated with the help of standard curve.

Exchangeable potassium (meq/100g soil): Exchangeable K was determined by 1N NH_4OAC (pH 7.0) extract of the soil by using flame photometer (Black, 1965).

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

3.22 Chemical analysis of plant samples

3.22.1 Preparation of plant samples

Plant samples were collected immediately after harvest of the crop. Cobs and plants were cleaned with distilled water and dried at first in the sun light and then in an oven at 65^0C for 48 hours. The dried samples were then ground with a grinder. The prepared samples were then put into small paper bags and kept into a dessicator till being used.

3.22.2 Digestion of plant samples with sulphuric acid

For N determination an amount of 0.1 g plant sample (grain/straw) was taken into a 100 ml Kjeldahl flask. An amount of 1.1 g catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se = 100: 10: 1), 2 ml 30% H_2O_2 and 3 ml conc. H_2SO_4 were added into the flask. The flask was swirled and allowed to stand for about 10 minutes; followed by heating at 200^0 C. Heating was continued until the digest was clear, and colorless. After cooling, the contents were taken into a 100 ml volumetric flask and the volume was made with distilled water. Reagent blank was prepared in a similar way. This digest was used for determining the nitrogen contents in plant samples.

3.22.3 Digestion of plant samples with nitric-perchloric acid mixture

An amount of 0.5 g of plant sample was taken into a dry clean 100 ml. Kjeldahl flask and added 10 ml of di-acid mixture heated to colourless digest and taken into 100 ml volumetric flask.

3.22.4 Determination of elements in the digest

Nitrogen, P, K and S contents in the digest were determined by similar method as described in the soil analysis.

3.23 Statistical Analysis

The collected data were statistically analyzed by using the ANOVA technique. The test of significance of all parameters was done. The Duncan`s Multiple Range Test (DMRT) with Least Significant Difference value was determined with appropriate levels of significance and the means were tabulated. The mean comparison was carried out by DMRT technique (Gomez and Gomez, 1984).

Chapter 4
Results and Discussion

Chapter 4

RESULTS AND DISCUSSIONS

This chapter includes the experimental results on the effects of P and S on plant height, cob length, circumference of cob, plant weight, number of cobs/plant, number of grains/cob, shelling percentage, grain yield, stover yield, nutrient content in plant, nutrient uptake by plant and nutrient status in post harvest soil. The results are presented in Table 4-15. Five photographs of experimental plot are presented in Fig. 3, 4, 5, 6 and 7 and three graphs are shown in Appendix Fig. I, II and III. The results are discussed characterwise under the following heads.

4.1 Effect of P and S on plant characters

4.1.1 Plant height

Individual effect of phosphorus

Plant height varied significantly with different levels of phosphorus (Table 4). The tallest plant (213.9cm) was found when the crop was fertilized with 50 Kg P/ha which was statistically identical with P_{35} treatments and the smallest plant (196.3cm) was recorded with 0 kg P/ha.

Individual effect of sulphur

Plant height was not significantly different with different levels of sulphur (Table 5). However, numerically the maximum plant height (212.1 cm) was found with 40 Kg S/ha and minimum plant height (203.2 cm) was recorded with 25 Kg S/ha.

Combined effect of P and S

The combined effect of phosphorus and sulphur showed significant effect on plant height (Table 6). The highest plant height (224.6cm) was obtained in the treatment combination$P_{50}S_{40}$ and the lowest plant height (183.3cm) was recorded in the treatment where no P and S were applied (P_0S_0).

Table 4. Effect of different levels of phosphorus on the growth and yield contributing characters of maize plant.

Phosphorus (kg/ha)	Plant height (cm)	Cob length (cm)	Cobs /plant	Grain /cob	Circumference of cob (cm)	1000-Grain weight (gm)	Grain yield (t/ha)	Stover yield (t/ha)	Shelling percentage
P_0	196.3b	21.33	1.542	495.8ab	17.51	278.3c	8.643	12.70c	71.86
P_{35}	210.6a	21.69	1.583	478.7ab	17.60	288.2bc	9.783	14.43bc	72.43
P_{50}	213.9a	22.83	1.817	513.9a	18.99	320.7a	11.52	16.50a	72.86
P_{65}	207.9ab	21.98	1.633	463b	18.02	292.8ab	10.41	15.00ab	71.69
Level of significance	0.01	NS	NS	0.01	NS	0.01	0.01	0.01	NS

In a column figures having similar letter(s) do not differ significantly

Table 5. Effect of different levels of sulphur on the growth and yield contributing characters of maize plant.

Sulphur (kg/ha)	Plant height (cm)	Cob length (cm)	Cobs/ plant	Grain/ cob	Circumference of cob (cm)	1000-Grain weight (gm)	Grain/yield (t/ha)	Stover yield (t/ha)	Shelling percentage
S_0	204.6	21.69	1.575	468.3	18.02	277.5 c	9.217 b	13.39 b	72.44
S_{25}	203.2	21.68	1.592	480.2	17.60	294.1 b	9.523 b	14.31 ab	70.82
S_{40}	212.1	22.67	1.800	514.3	18.53	307.4 a	11.27 a	16.06 a	73.79
S_{55}	208.9	21.78	1.608	488.9	17.98	301.0 ab	10.35 ab	114.86 ab	71.79
Level of significance	NS	NS	NS	NS	NS	0.01	0.01	0.01	NS

In a column figures having similar letter(s) do not differ significantly

Table 6. Combined effect of different levels of P and S on the growth and yield contributing characters of maize plant.

P × S fertilizer(kg/ha)	Plant Height (cm)	Cob Length (cm)	Cobs/ plant	Grain/ Cob	Circumference of cob	1000-Grain weight (gm)	Grain yield (t/ha)	Stover yield (t/ha)	Shelling (%)
$P_0 S_0$	183.3d	20.03e	1.000 c	428.3 h	17.23 d	239.4	5.367	8.050e	70.47
$P_0 S_{25}$	190d	20.80d	1.533 b	497.0 b-e	17.20 d	276.7	7.407	12.19d	70.31
$P_0 S_{40}$	205.3c	23.41ab	2.000 a	594.7 a	18.10 bcd	313.5	12.37	6.27b	74.15
$P_0 S_{55}$	206.3bc	21.07de	1.633ab	508.0 bcd	17.50 cd	283.9	9.433	4.30c	72.52
$P_{35} S_0$	205c	21.25cde	1.700ab	452.3 fgh	17.87 bcd	274.9	10.00	4.85bc	73.81
$P_{35} S_{25}$	210.7bc	21.77bcde	1.567ab	494.0 b-f	17.70 cd	282.4	9.830	14.48bc	70.12
$P_{35} S_{40}$	214abc	21.10de	1.467 b	498.3 b-e	17.33 cd	291.8	9.093	13.84c	74.25
$P_{35} S_{55}$	212.7bc	22.63abcd	1.600ab	470.0 d-g	17.50 cd	303.8	10.20.	14.54bc	71.55
$P_{50} S_0$	217.7ab	23.03abc	2.00 a	527.3 ab	18.73 bc	311.6	11.69	16.21b	73.80
$P_{50} S_{25}$	206.9bc	22.28bcd	1.667ab	480.7 c-g	17.67 cd	311.3	10.63	15.71bc	72.21
$P_{50} S_{40}$	224.6a	24.13a	2.000 a	534.3 ab	20.38 a	335.9	12.71	18.40a	73.74
$P_{50} S_{55}$	206.7bc	21.87bcd	1.600ab	513.3 abc	19.17 b	323.8	11.05	15.67bc	71.71
$P_{65} S_0$	212.3bc	22.47abcd	1.600ab	465.3 e-h	18.23 bcd	284.1	9.813	14.45bc	71.69
$P_{65} S_{25}$	205.3c	21.87bcd	1.600ab	449.0 gh	17.83 bcd	306.1	10.22	4.88bc	70.65
$P_{65} S_{40}$	204.3c	22.03bcd	1.733ab	474.7 c-g	18.30 bcd	288.5	10.91	15.72bc	73.03
$P_{65} S_{55}$	209.7bc	21.57cde	1.600ab	464.3 e-h	17.73 cd	292.7	10.71	14.94bc	71.40
Level of significance	0.01	0.01	0.01	0.01	0.01	NS	NS	0.01	NS

In a column figures having similar letter(s) do not differ significantly

4.1.2 Cob length

Individual effect of phosphorus

Cob length was not significantly affected by phosphorus levels (Table 4).The highest cob length(22.83cm) was found with 50 kg P/ha .The lowest cob length (21.33cm) was obtained with 0 kg P/ha.

Individual effect of sulphur

Cob length was not significantly affected by sulphur levels (Table 5). However, numerically the longest cob (22.67cm) was found with 40 kg S/ha and the shortest cob length (21.68cm) was obtained with 25 kg S/ha.

Combined effect P and S

Cob length was significantly influenced by the combined application of P and S at various levels (Table 6). The highest cob length (24.13cm) was obtained in the treatment combination of $P_{50}S_{40}$ and the lowest one (20.03cm) was obtained in the treatment were no P and S was applied (P_0S_0).

4.1.3 Circumference of cob

Individual effect of phosphorus

There was no significant difference in the circumference of cob among the phosphorus levels (Table 4). The highest circumference of cob (18.99cm) was recorded with 50 kg P/ha. The lowest circumference of cob (17.51cm) was obtained with 0 kg P/ha.

Individual effect of sulphur

Circumference of cob was not significantly affected with sulphur fertilization (Table 5). However, numerically the highest circumference (18.53cm) was found with 40 kg S/ha and the lowest circumference (17.60cm) was obtained with 25 kg S/ha.

Combined effect of P and S

Circumference of cob showed significant variation due to the combined application of P and S at various levels (Table 6). The maximum and the minimum circumference of cob were obtained with $P_{50}S_{40}$ and P_0S_{25} treatment combinations, respectively.

4.2 Effect of P and S on the yield and yield components

4.2.1 Number of cobs/plant

Individual effect of phosphorus

The number of cobs per plant was not significantly influenced by different phosphorus levels. However, numerically maximum number of cobs per plant (1.817) was obtained with 50 kg P/ha and minimum number of cobs per plant 1.54 with 0 kg P/ha (Table 4). Therefore, it was observed that number of cobs per plant increased with increasing phosphorus levels.

Individual effect of sulphur

The number of cobs per plant was not significantly influenced by different sulphur levels. However, numerically maximum number of cobs per plant (1.80) was found with 40 kg S/ha and minimum number of cobs per plant (1.5) with 0 kg S/ha (Table 5).

Combined effect of P and S

The combined effects of P and S at various levels showed significant influence on the number of cobs per plant. The highest number of cobs per plant (2.00) were recorded in the treatment combination of ($P_{50}S_{40}$), ($P_{50}S_0$), (P_0S_{40}) and the lowest number of cobs per plant (1.00) was recorded in the treatment where no P and S were applied.

4.2.2 Number of grains/cob

Individual effect of phosphorus

The number of grains per cob was significantly influenced by different phosphorus levels. The highest number of grains per cob (513.9) was found with 50 kg P/ha which was statistically identical to P_0 and P_{35} treatments (Table 4). The lowest number of grains per cob (463.3) was obtained with 65 kg P/ha which indicated a suppressive effect on grain due to increased application of P.

Individual effect of sulphur

The number of grains per plant was not significantly influenced by different sulphur levels. However, numerically maximum number of cobs per plant (514.3) was found with 40 kg S/ha and minimum number of grains per plant 468.3 with 0 kg S/ha (Table 5).

Combined effect of P and S

The combined effects of P and S fertilizers showed the significant effect on the number of grains per cob. The highest number of grains per cob (549.7) was obtained in the treatment combination P_0S_{40} and the lowest number of grain per cob (428.3) was obtained in the control plot (Table 6).

4.2.3 Weight of 1000-grain

Individual effect of phosphorus

Phophosrus had significant effect on the weight of 1000-grain. The highest of 1000-grain weight (320.7g) was obtained by the application of 50 kg P/ha which was statistically identical to 65 kg P/ha and the lowest one (278.3 g) was recorded where no P was applied (Table 4).

Individual effect of sulphur

There was a significant influence on weight of 1000-grain by sulphur application. The highest 1000-grain weight (307.4g) was recorded with 40 kg S/ha which was statistically identical to 55 kg S/ha and the lowest one (277.5 g) was recorded with 0 kg S/ha (Table 5).

Combined effect of P and S

The combined effect of phosphorus and sulphur levels failed to show the significant effect on the weight of 1000-grain. However, numerically the highest weight of 1000-grain (335.9 g) was found in the treatment combination of ($P_{50}S_{40}$) and the lowest one (239.4 g) in the treatment were no P and S were applied (Table 6).

4.2.4 Shelling percentage

Individual effect of phosphorus

Phosphorus fertilizer showed not significantly variable effect on shelling percentage. The highest shelling percentage (72.86%) was observed by the application of 50 kg P/ha and the lowest one (71.69%) was observed by the application of 0 kg P/ha (Table 4). Therefore, increasing shelling percentage was observed with increasing phosphorus levels. Similar result was reported by Hammam (1995).

Individual effect of sulphur

Shelling percentage was not significantly influenced by sulphur levels. However, numerically the highest shelling percentage (73.79%) was found with 40 kg S/ha and the lowest shelling percentage (70.82%) was found with 25 kg S/ha (Table 5).

Combined effect of P and S

The combined effects of P and S levels failed to show significant effect on the shelling percentage. However, numerically the highest shelling percentage (74.25%) was found in the treatment combination of ($P_{35}S_{40}$) and the lowest one (70.12%) was found in the combination of $P_{35}S_{25}$ (Table 6).

4.2.5 Grain yield (t/ha)

Individual effect of phosphorus

Grain yield did not show significant variation due to different levels of phosphorus application (Table 4). It was noted that application of phosphorus increased the grain yield over no phosphorus application .Among the treatments, the highest grain yield (11.52 t/ha) was obtained by the application of 50 kg P/ha and the lowest yield (8.643 t/ha) was achieved with 0 kg P/ha (Table 4 and Appendix Fig. I). Application of 50 kg P/ha produced maximum number of grains/cob, 1000-grain weight, which resulted the highest grain yield compared with other treatments.

Individual effect of sulphur

Sulphur treatment had a significant influence on grain yield of maize. The maximum grain yield (11.27 t/ha) was obtained by the application of 40 kg S/ha which was statistically identical to 55 kg S/ha. The minimum grain yield (9.21 t/ha) was obtained by no sulphur application (Table 5 and Appendix Fig. II). Therefore, it was observed that grain yield was increased with increasing level of sulphur. This result was in agreement with Sinha *et al.* (1995) who reported that grain yield increased with S application. Similar result was also reported by Talukder and Islam (1982).

Combined effect of P and S

The combined effects of P and S had no significant influence on grain yield (Table 6 and Appendix Fig. III). However, the highest grain yield (12.71 t/ha) was obtained in the treatment combination of $P_{50}S_{40}$ and the lowest grain yield (5.367 t/ha) was obtained in the treatment combination where no P and S were applied.

4.2.6 Stover yield

Individual effect of phosphorus

Stover yield significantly varied due to phosphorus application (Table 4). The highest stover yield (16.50 t/ha) was obtained by the application of 50 kg P/ha and the lowest (12.70 t/ha) with 0 kg P/ha (Table 4 and Appendix Fig. I).

Individual effect of sulphur

Sulphur treatments showed significant influence on stover yield (Table 5 and Appendix Fig II). The highest stover yield (16.06 t/ha) was found with 40 kg S/ha and the lowest stover yield (13.39 t/ha) was found with 0 kg S/ha.

Combined effect of P and S

Stover yield significantly varied due to the combined effect of phosphorus and sulphur levels (Table 6 and Appendix Fig.III). The highest stover yield (18.40 t/ha) was obtained in the treatment combination of $P_{50}S_{40}$ and the lowest stover yield (8.05 t/ha) was obtained in the control treatment (P_0S_0).

Fig. 4 Photograph showing the maize plant in the control plot.

Fig. 5 Photograph showing the maize plant in plot of $P_{50}S_0$ treatment.

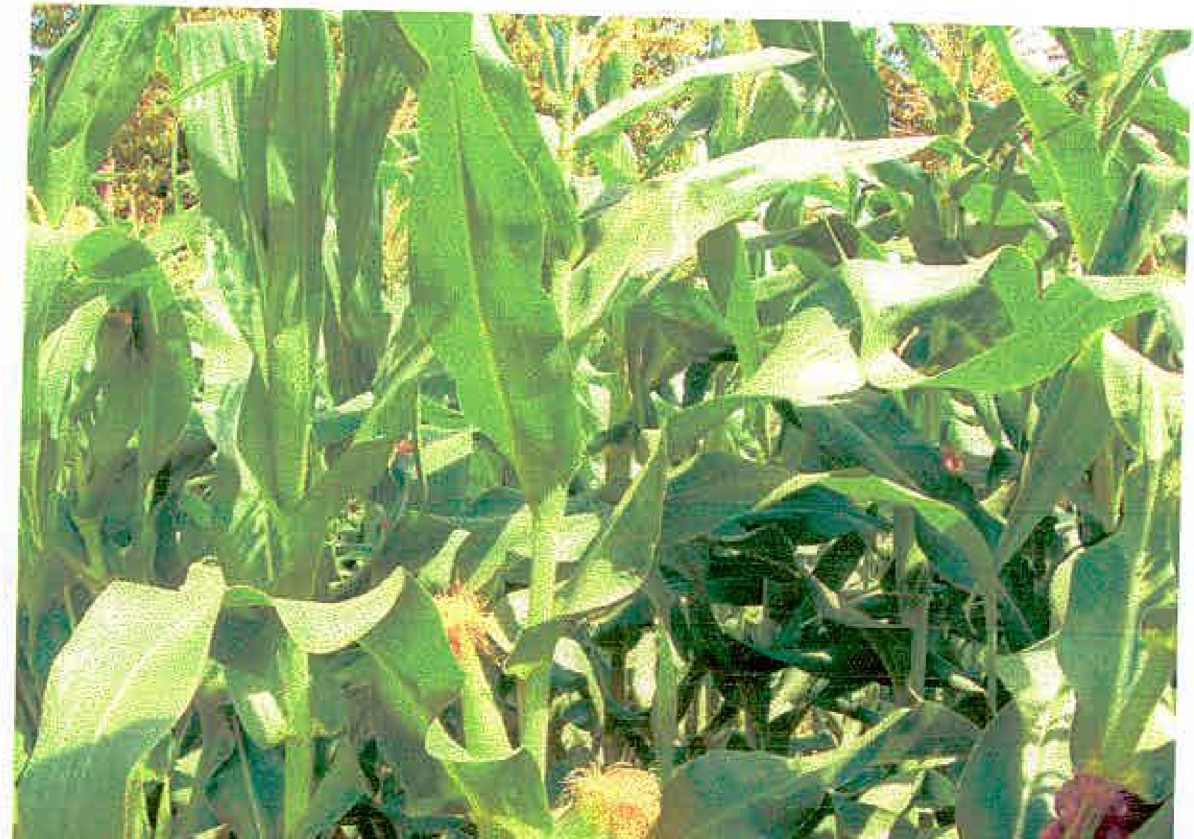

Fig. 6 Photograph showing the maize plant in plot of P_0S_{40} treatment.

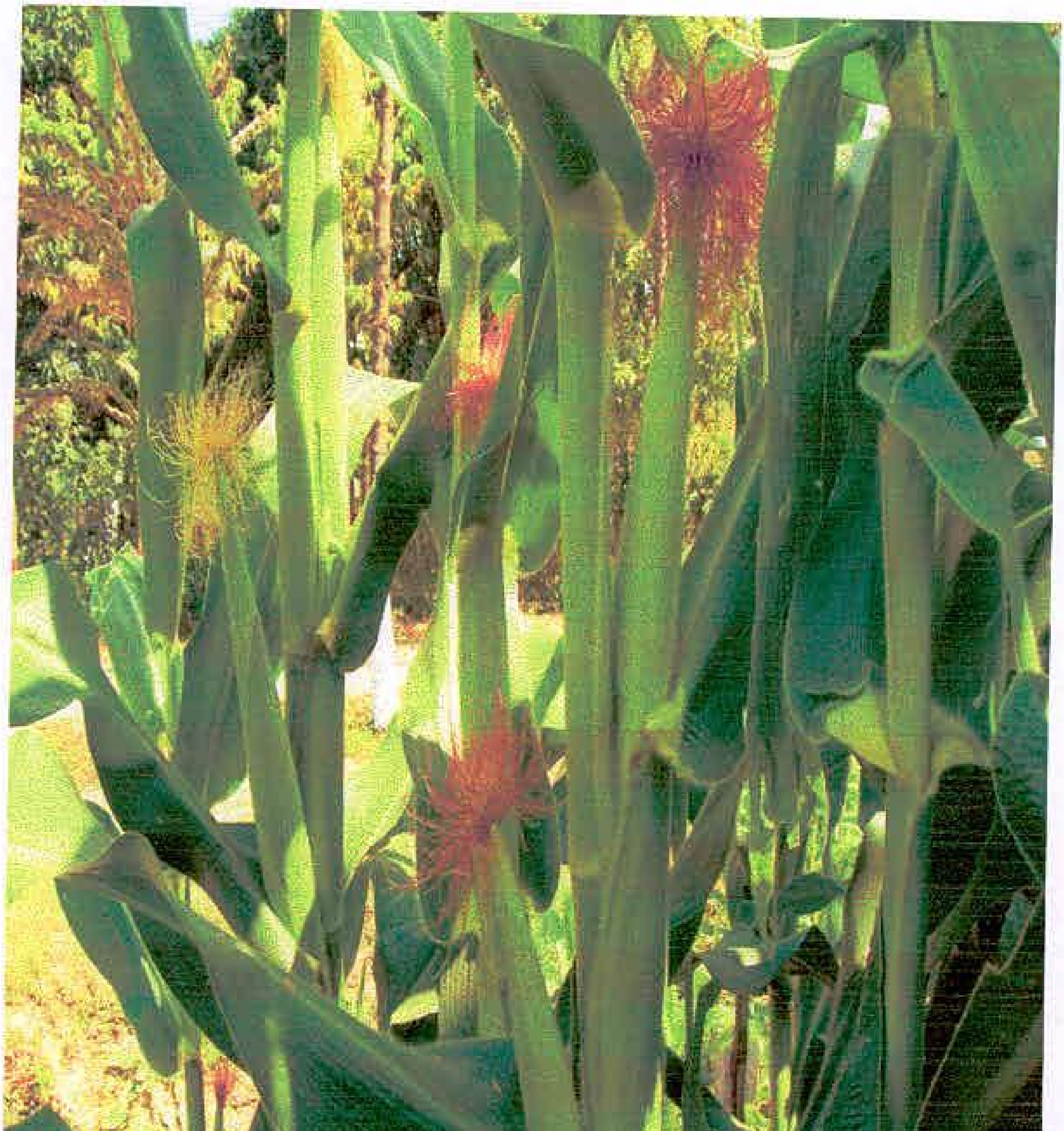

Fig. 7 Photograph showing the maize plant in plot of $P_{50}S_{40}$ treatment.

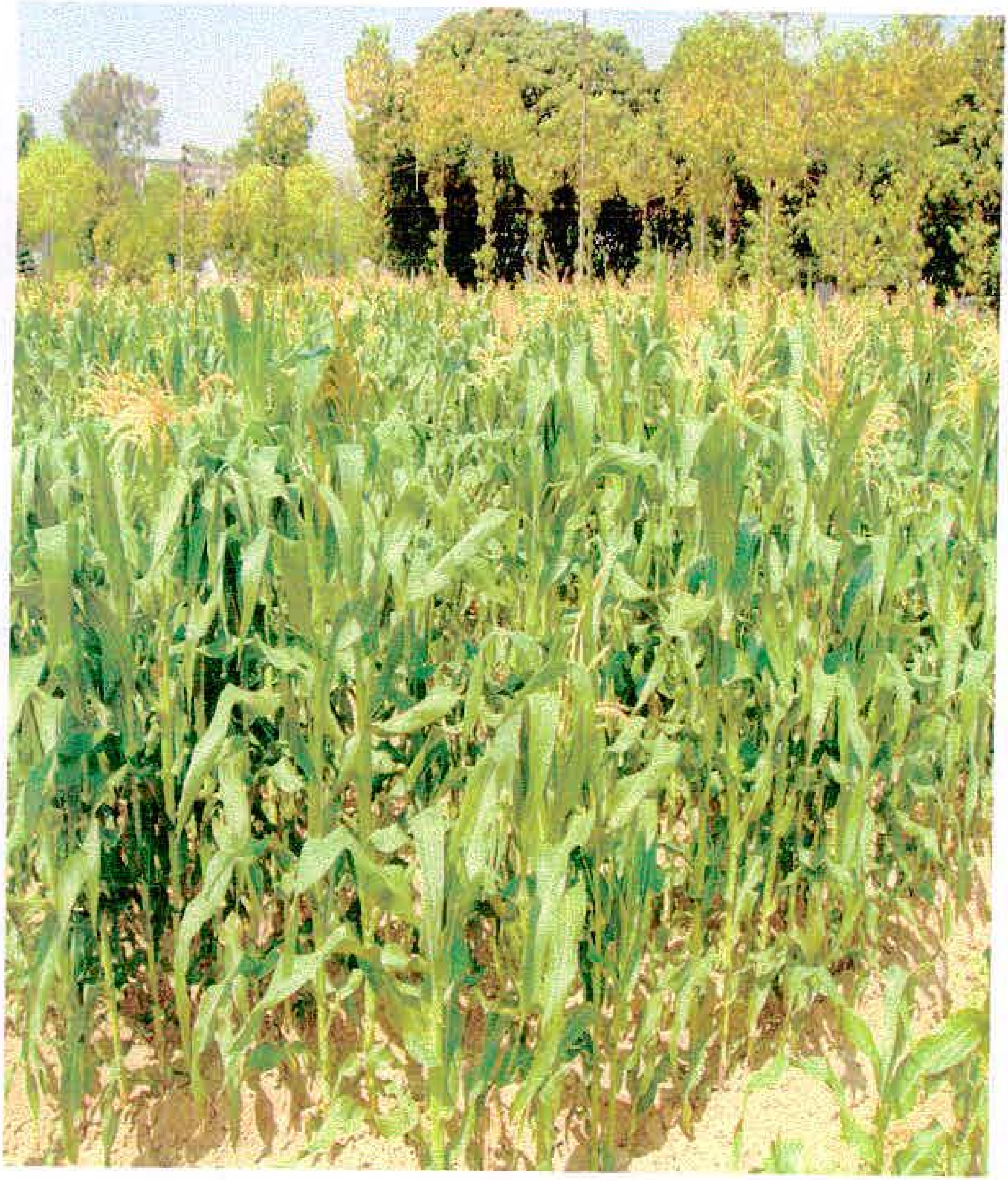

Fig. 8 Photograph showing the whole experimental plot.

4.3. Effect of P and S on the nutrient contents in maize plant.

4.3.1 N content

The N content in plant was not statistically significant due to different treatments of phosphorus (Table 7). The N content in plant at different P treatments ranged from 1.122 to 1.225 % .The highest N content in plant (1.225 %) was observed in P_{35} treatment and the lowest N content in plant (1.122%) was noted in control.

Nitrogen content in plant did not show significant influence by different sulphur level (Table 8). The N content in plant at different S treatments ranged from 1.095 to 1.283 %. The highest N content in plant (1.283 %) was observed in S_{40} treatment and the lowest N content (1.095 %) was noted in S_{55}. The low content of N at the highest level of S indicated an antagonistic effect of S at its highest level on the content of N in maize plant.

The combined effect of P and S on N content in plant was significant (Table 9). The N content in plant ranged from 1.02%to 1.41%. The highest N content (1.41 %) was obtained with $P_{35}S_{40}$ treatment. The minimum N content in stover (1.02%) was found in P_0S_{55}.

4.3.2 P content

A significant increase in P content in plant was recorded due to different treatments of phosphorus (Table 7). The P content ranged from 0.5238 to 0.7778 %. The highest value (0.7778 %) was obtained in P_{65} treatment and the minimum P content (0.5238 %) was obtained in control treatment. Increase in the rates of P showed significant increase in the P content in maize plant.

Phosphorus content in stover was also influenced by different levels of S (Table 8). Phosphorus content in stover ranged from 0.6068 % to 0.6815 %. The highest Phosphorus content of straw (0.6815 %) was found in S_{25} kg/ha. The lowest

Phosphorus content in stover (0.6068 %) was found in S_{55} which indicated a suppressive effect of S at its high level on the P content in maize plant.

The treatment combinations of phosphorus and sulphur significantly influenced the phosphorus content in stover (Table 9). Phosphorus content in straw was ranged from 0.4900% to 0.9870 %. The maximum P content (0.9870 %) in stover was found in $P_{65}S_{25}$ treatment and the minimum phosphorus content (0.4900 %) was observed in P_0S_{25} treatments. Combined application of P at high level with high levels of S showed an antagonistic effect on the content of P in maize plant.

4.3.3 K content

A significant increase in K content in stover was recorded due to different treatments of phosphorus (Table 7). The K content ranged from 0.7280 % to 0.8487 %. The highest value (0.8487 %) was obtained in P_{65} treatment and the minimum value (0.7280 %) was obtained in control treatment.

Table 7. Effect of different levels of P fertilizer on the NPKS concentration in maize plant.

Fertilizer	Concentration (%)			
	Nitrogen	Phosphorus	Potassium	Sulphur
P_0	1.122	0.5238 c	0.7280 c	0.3955 a
P_{35}	1.225	0.5972 b	0.7553 b	0.4142 a
P_{50}	1.150	0.6158 b	0.6785 d	0.4110 a
P_{65}	1.153	0.7778 a	0.8487 a	0.3185b
Level of significance	NS	0.01	0.01	0.01

In a colum figures having similar letter(s) don't differ significantly

Table 8. Effect of different levels of S fertilizer on the NPKS concentration in maize plant.

Fertilizer	Concentration (%)			
	Nitrogen	Phosphorus	Potassium	Sulphur
S_0	1.157	0.6482 b	0.8127 a	0.3960
S_{25}	1.115	0.6815 a	0.7648 c	0.3792
S_{40}	1.283	0.5780 d	0.7868 b	0.3755
S_{55}	1.095	0.6068 c	0.6463 d	0.3885
Level of significance	NS	0.01	0.01	NS

In a colum figures having similar letter(s) don't differ significantly

Potassium content in stover was significantly influenced by different levels of S (Table 8). Potassium content in stover ranged from 0.6463 % to 0.8127 %. The highest potassium content in stover (0.8127 %) was found in control treatment and the lowest potassium content in stover (0.6463 %) was found with the S_{55} kg/ha treatment. Application of S at high levels showed antagonistic effect on the content of K in maize plant.

Potassium (K) content in stover was significantly influenced by the combined effect of P and S (Table 9). Potassium content in stover was ranged from 0.4750 % to 0.9717 %. The maximum potassium content in stover (0.9717 %) was found in $P_{65}S_{40}$ treatment and the minimum potassium content in stover (0.4750 %) was observed in P_{50} S_{55} treatment. Combined application of highest P and S doses showed an antagonistic effect on the K content in maize plant.

Table 9. Combined effect of different doses of P and S fertilizers on the NPKS concentrations in maize plant

Phosphorus X Sulphur fertilizer	Concentration (%)			
	Nitrogen	Phophorus	Potassium	Sulphur
P_0 S_0	1.027cd	0.5210i	0.6620i	0.3750e
P_0 S_{25}	1.030cd	0.4900j	0.7510g	0.3450f
P_0 S_{40}	1.250 b	0.5220i	0.8870c	0.3850e
P_0 S_{55}	1.020d	0.5620h	0.6120j	0.4770b
P_{35} S_0	1.160bcd	0.5870g	0.8120e	0.3850e
P_{35} S_{25}	1.200bc	0.6120f	0.7710f	0.5170 a
P_{35} S_{40}	1.410a	0.5150i	0.6133j	0.3800e
P_{35} S_{55}	1.130bcd	0.6750c	0.8250e	0.3750e
P_{50} S_0	1.200bc	0.5230i	0.8520d	0.4070d
P_{50} S_{25}	1.130bcd	0.6370de	0.7120h	0.3800e
P_{50} S_{40}	1.140bcd	0.6250ef	0.6750i	0.4350c
P_{50} S_{55}	1.130bcd	0.6780c	0.4750 k	0.4220d
P_{65} S_0	1.240b	0.9620b	0.9250b	0.4170d
P_{65} S_{25}	1.100bcd	0.9870 a	0.8250c	0.2750 h
P_{65} S_{40}	1.170bcd	0.6500d	0.9717 a	0.3020g
P_{65} S_{55}	1.100bcd	0.5123i	0.6733i	0.2800 h
Level of significance	0.01	0.01	0.01	0.01

In a colum figures having similar letter(s) don't differ significantly

4.3.4 S content

A significant increase in S content in stover was recorded due to different treatments of P (Table 7). The S content ranged from 0.3185 % to 0.4142 %. The highest value (0.4142 %) was obtained in P_{35} treatment which was statistically similar with P_0 and P_{50}. The minimum value (0.3185 %) was obtained with P_{65}, which showed antagonistic effect of high P dose on S content in maize plant.

Sulphur content in stover was not significantly influenced by different levels of S (Table 8).

The combined effect of P and S on S content in stover was significantly influenced (Table 9). Sulphur content in stover was ranged from 0.2750 % to 0.5170 %. The maximum sulphur content (0.5170 %) in stover was found in $P_{35}S_{25}$ treatment and the minimum sulphur content (0.2750 %) was observed in P_{65} S_{25} treatments. This showed antagonistic effect of P and S on S content when P at high level was applied.

4.4 Effect of Phosphorus and Sulphur on nutrient uptake by maize plant.

4.4.1 Nitrogen uptake

The N uptake by the stover of maize was found statistically significant due to different treatments of phosphorus (Table10). The N uptake by stover due to different treatments ranged from 145.7 kg/ha to 189.1 kg/ha .The highest N uptake (189.1 kg ha^{-1}) was observed in P_{50} treatment and the lowest N uptake (145.7 kg ha^{-1}) was noted in P_0. Application of P at its highest level (P_{65}) showed a suppressive effect on the N uptake by the maize plant.

Nitrogen uptake by stover was significantly affected by different sulphur levels (Table 11). The N uptake by stover due to different S treatments ranged from 156.5 kg/ha to 204.5 kg/ha .The highest N uptake (204.5 kg ha^{-1}) was observed in S_{40} treatment and the lowest N uptake (156.5 kg ha^{-1}) was noted in S_0. S at the highest (S_{55}) dose of application showed a negative effect on the uptake of N by maize plant.

The combined effect of P and S on N uptake by stover was statistically significant (Table 12). The N uptake by stover ranged from 82.16 kg/ha 229.4 kg/ha. The highest N uptake (229.4 kg/ha) was obtained with P_0S_{40} treatment. The minimum N uptake by stover (82.16 kg/ha) was found in control treatment (P_0S_0).

Table 10. Effect of different levels of P on nutrient uptake by maize plant.

Fertilizer	Nutrient uptake by stover (kg/ha)			
	Nitrogen	Phosphorus	Potassium	Sulphur
P_0	145.7 c	66.67 d	94.08 b	50.72 c
P_{35}	176.2 b	86.22c	100.7 ab	59.72 b
P_{50}	189.1 a	101.3b	111.7 ab	67.79 a
P_{65}	172.7 b	116.2 a	127.3 a	47.61 c
Level of significance	0.01	0.01	0.01	0.01

In a column, figures having similar letter(s) don't differ significantly

Table 11. Effect of different levels of S on nutrient uptake by maize plant.

Fertilizer	Nutrient uptake by stover (kg/ha)			
	Nitrogen	Phosphorus	Potassium	Sulphur
S_0	156.5 b	88.00 b	110.8 ab	53.18 c
S_{25}	160.0 b	98.77 a	101.0 ab	54.33 bc
S_{40}	204.5 a	93.33 ab	126.5 a	60.68 a
S_{55}	162.9b	90.32 b	95.54 b	57.67 ab
Level of significance	0.01	0.01	0.01	0.01

In a colum figures having similar letter(s) don't differ significantly

4.4.2 Phosphorus uptake

Phosphorus uptake by the stover of maize was found statistically significant due to different treatments of phosphorus (Table 10). The P uptake by stover due to different treatments ranged from 66.67 kg/ha to 116.2 kg/ha .The highest P uptake (116.2 kg ha^{-1}) was observed in P_{65} treatment and the lowest P uptake (66.67 kg ha^{-1}) was noted in P_0. The uptake of P showed increase with increase in the levels of P.

Phosphorus uptake by stover was significantly affected by different sulphur levels (Table 11). Phosphorus uptake by stover was ranged from 88.00 kg/ha to 98.77 kg/ha. The highest P uptake by stover (98.77 kg/ha) was found in S_{25} treatment and lowest P uptake (88.00 kg/ha) was found with S_0 treatment. Application of S at its higher levels showed a negative effect on the uptake of P by the maize plant.

The treatment combinations of phosphorus and sulphur significantly influenced the phosphorus uptake by stover (Table 12). Phosphorus uptake by stover was ranged from 41.68 kg/ha to 146.9 kg/ha. The highest P uptake by stover (146.9 kg/ha) was obtained from the treatment $P_{65}S_{25}$ and the lowest values (41.68 kg/ha) was obtained from control treatment (P_0S_0). The highest level of P (P_{65}) combined with higher S levels (S_{40} and S_{55}) showed an antagonistic effect on the P uptake by maize plant

4.4.3 Potassium uptake

Effect of phosphorus levels on K uptake by stover responded significantly due to different treatments (Table 10) and ranged from 94.08 kg ha^{-1} to 127.3 kg ha^{-1}. The highest K uptake (127.3 kg ha^{-1}) was noted in P_{65} treatment and the lowest value (94.08 kg ha^{-1}) was found in P_0. K uptake by plant showed a progressive increase with the increase in the levels of P.

Potassium uptake by stover was significantly influenced by different S levels (Table 11) and ranged from 95.54 to 126.5 kg ha^{-1}. The highest K uptake by stover (126.5 kg/ha) was found with S_{40} treatment and the lowest value (65.54 kg ha^{-1}) was found in S_{55}, which indicated an antagonistic effect of S at its high level on the uptake of K by maize plant.

Table 12. Combined effect of different levels of P and S fertilizers on nutrient uptake by maize

Phosphorus X Sulphur fertilizers	Nutrient uptake by stover (kg/ha)			
	Nitrogen	Phophorus	Potassium	Sulphur
$P_0 S_0$	82.16 i	41.68 k	52.96 g	30.01k
$P_0 S_{25}$	125.6h	59.71j	91.54ef	42.05j
$P_0 S_{40}$	203.37 a	84.92fg	144.3ab	62.63de
$P_0 S_{55}$	145.9g	80.36gh	87.51ef	68.21c
$P_{35} S_0$	172.3e	87.16f	120.6bcd	57.17fg
$P_{35} S_{25}$	173.1e	88.31f	77.92fg	74.60b
$P_{35} S_{40}$	195.1c	71.27i	84.88ef	52.58h
$P_{35} S_{55}$	164.3f	98.14e	119.6bcd	54.52gh
$P_{50} S_0$	192.3c	83.88fg	136.3abc	65.28cd
$P_{50} S_{25}$	177.5de	100.2e	111.9cde	59.74ef
$P_{50} S_{40}$	209.7b	115.0c	124.2bcd	80.04 a
$P_{50} S_{55}$	177.2de	106.2d	74.43fg	66.12cd
$P_{65} S_0$	179.2de	139.3b	133.4abc	60.25ef
$P_{65} S_{25}$	163.7f	146.9 a	122.7bcd	40.92j
$P_{65} S_{40}$	183.8d	102.1de	152.5 a	47.46i
$P_{65} S_{55}$	164.3f	76.53h	100.6def	41.82j
Level of significance	0.01	0.01	0.01	0.01

In a colum figures having similar letter(s) don't differ significantly

Potassium (K) uptake by stover was significantly affected by the combined effect of phosphorus and sulphur (Table 12). The K uptake ranged from 52.96 to152.5 kg ha^{-1}. The treatment combination $P_{65}S_{40}$ gave the highest K uptake by stover (152.5 kg/ha), which was significantly different from other treatments. The lowest K uptake by (52.96 kg/ha) was found in control treatment (P_0S_0).

4.4.4 Sulphur uptake

Effect of phosphorus levels on S uptake by maize stover responded significantly due to different treatments of P. The S uptake ranged from 47.61 to 67.79 kg ha^{-1} (Table 10). The highest S uptake (67.79 kg ha^{-1}) was obtained in P_{50} treatment and the lowest value (47.61 kg ha^{-1}) was found in P_{65} which is an indication of the suppressive effect of high P dose (P_{65}) on the uptake of S by maize plant.

Sulphur uptake by stover was significantly influenced by different levels of S (Table 11). Sulphur uptake by straw ranged from 53.18 kg/ha to 60.68 kg/ha. The highest S uptake by stover (60.68 kg/ha) was found in S_{40} and the lowest S uptake by stover (53.18 kg/ha) was found in S_0 treatment.

Combined effect of different levels of phosphorus and sulphur on S uptake by stover was significantly influenced (Table12). Sulphur uptake by stover was ranged from 30.01 kg/ha to 80.04 kg/ha. The maximum sulphur uptake by stover (80.04 kg/ha) was found in $P_{50}S_{40}$ treatment and the minimum sulphur uptake (30.01 kg/ha) was observed in control treatment. Application of P and S at their highest levels ($P_{65}S_{55}$) showed an antagonistic effect on the uptake of S by the maize plant.

4.5 Effect of P and S on the characteristics of the post harvest soil

The characteristics of the post harvest soils as influenced by different treatments of P and S showed a marked variation on the soil organic carbon, N, P, K and S contents in soil.

4.5.1 Organic carbon content (%)

A significant variation was observed on the organic carbon content in soil after maize harvest where various levels of phosphorus was incorporated in soil .The organic carbon content of the post harvest soil ranged from 0.730 % to 1.269% (Table 13). The maximum organic carbon content (1.269%) was obtained in the P_{65} treatment and the minimum organic carbon content (0.73%) was obtained in the P_{50} treatment.

A significant variation was observed on the organic carbon content after maize harvest where different levels of sulphur were incorporated in soil. The organic carbon content in the post harvest soil ranged from 0.7825 % to 1.011% (Table 14). The maximum organic carbon content (1.011%) was obtained in the S_{40} treatment and the minimum organic carbon content (0.7825%) was obtained in the S_0 treatment.

Combined application of different doses of phosphorus and sulphur showed a significant effect on the organic carbon content in the postharvest soil (Table 15). The organic carbon content in the post harvest soil ranged from 0.82% to 1.763 %. The highest organic carbon content (1.763 %) was recorded in the treatment combination of P_{65} S_{55} and the minimum organic carbon content (0.82%) was obtained in the control treatment (P_0S_0).

4.5.2 Total nitrogen

A statistically significant variation was observed in the total N content in the post harvest soil. The total N content of the post harvest soil varied from 0.077 % to

0.082% (Table 13). The highest total N content (0.082%) was observed in P_{65} treatment and the lowest value of 0.077% in P_0 treatment.

Statistically significant variation was not observed in total N content of the post harvest soil (Table 14). The total N content of the post harvest soil ranged from 0.075% to 0.08250%. The highest total N content (0.08250%) was observed in S_{55} treatment and the minimum value (0.075%) was found in the S_0 treatment.

The effect of combined applications of different doses of phosphorus and sulphur resulted significant variations in nitrogen content in the post harvest soil (Table 15). The total N content in the post harvest soil ranged from 0.065% to 0.088%. The highest total N content of the post harvest soil (0.088%) was recorded in the treatment combinations of $P_{65} S_{55}$ which was statistically similar with treatment combinations of $P_0 S_{40}$, $P_{35} S_{25}$, $P_{35} S_{55}$, $P_{50}S_{55}$, $P_{65} S_{25}$, and $P_{65}S_{40}$ and the lowest value of 0.065% was obtained with $P_{35}S_{40}$ treatment.

Table 13. Effect of P on the soil organic carbon, total N, available P, exchangeable K and available S content in the soil after maize harvest.

Rates of Sulphur	Organic Carbon (%)	Total N (%)	Available P (%)	Exchangeable K (%)	Available S (%)
P_0	0.775 b	0.0770	0.00205	0.00820	0.001288
P_{35}	0.840 b	0.0787	0.0030	0.00840	0.001540
P_{50}	0.730 c	0.0800	0.00315	0.00900	0.001515
P_{65}	1.269 a	0.0820	0.00259	0.00925	0.001508
Level of significance	0.01	NS	NS	NS	NS

In a colum figures having similar letter(s) don't differ significantly

Table 14. Effect of S on the soil organic carbon, total N, available P, exchangeable K and available S content in the soil after maize harvest.

Sulphur fertilizer	Organic Carbon(%)	Total N (%)	Available P (%)	Exchangeable K (%)	Available S (%)
S_0	0.7825 b	0.07500 b	0.002426	0.008300	0.001463
S_{25}	0.8125 b	0.08100 ab	0.002591	0.008575	0.001405
S_{40}	1.0110 a	0.07925 ab	0.002626	0.009175	0.001413
S_{55}	1.008 a	0.08250 a	0.003150	0.008808	0.001570
Level of significance	0.01	0.01	NS	NS	NS

In a colum figures having similar letter(s) don't differ significantly

4.5.3 Available phosphorus

The effect of application of P at different levels showed no significant differences in respect of P content in soil after harvest (Table 13). The P content in post harvest soil ranged from 0.002050% to 0.003150% .The highest P content was recorded in P_{50} treatment and the lowest P content was found in the P_0 treatment.

Statistically significant variation was not observed due to the application of S at different doses on the content of available P of the post harvest soil (Table 14).The P content in the post harvest soil ranged from 0.002426% to 0.003150%. The highest P content (0.003150%) was observed in S_{55} treatment and the minimum value (0.002426%) was found in the S_0 treatment.

The effect of combined application of phosphorus and sulphur showed no significant differences in respect of P content in soil after harvest (Table 15). The P content in the post harvest soil ranged from 0.00180% to 0.00420%. The highest P content was observed in $P_{50}S_{55}$ treatment and the minimum value was found in the P_0S_{25} treatment.

Table 15. Combined effect of P and S fertilizer on the soil organic carbon, total N, available P, exchangeable K and available S content in the soil after maize harvest.

Phosphorus X Sulphur fertilizers	Organic Carbon (%)	Total N (%)	Available P (%)	Exchangeable K (%)	Available S (%)
P_0 S_0	0.8200cd	0.07500de	0.002100	0.008200	0.001000
P_0 S_{25}	0.7600d	0.07600de	0.001800	0.008000	0.001220
P_0 S_{40}	0.7600d	0.08400ab	0.002400	0.008700	0.001450
P_0 S_{55}	0.7600d	0.07300e	0.001900	0.007900	0.001480
P_{35} S_0	0.8500c	0.08000bcd	0.002300	0.007800	0.001560
P_{35} S_{25}	0.8200d	0.08600ab	0.003400	0.008600	0.001700
P_{35} S_{40}	0.8500c	0.06500f	0.002900	0.008700	0.001300
P_{35} S_{55}	0.8400cd	0.08400ab	0.003400	0.008500	0.001600
P_{50} S_0	0.6600e	0.07800de	0.002900	0.008900	0.001560
P_{50} S_{25}	0.8300cd	0.07500de	0.002700	0.008300	0.001700
P_{50} S_{40}	0.7600d	0.08200abc	0.002800	0.009600	0.001300
P_{50} S_{55}	0.6700e	0.08500ab	0.004200	0.009200	0.001500
P_{65} S_0	0.8000cd	0.06700f	0.002403	0.008300	0.001733
P_{65} S_{25}	0.8400cd	0.08700a	0.002463	0.009400	0.001000
P_{65} S_{40}	1.6730b	0.08600ab	0.002403	0.009700	0.001600
P_{65} S_{55}	1.763a	0.08800a	0.003100	0.009633	0.001700
Level of significance	0.01	0.01	NS	NS	NS

In a colum figures having similar letter(s) don't differ significantly

4.5.4 Available potassium

The effect of application of P showed no significant differences in respect of K content in soil after harvest (Table 13). The K content in post harvest soil ranged from (0.0082% to .0.00925 %).The highest K content was recorded in P_{65} treatment and the lowest K content was found in the P_0 treatment.

Statistically significant variation was not observed in K content of the post harvest soil with the application of various levels of S (Table 14). The K content of the post harvest soil ranged from 0.0083 % to 0.0091 %. The highest K content was observed in S_{40} treatment and the minimum value was found in the S_0 treatment.

The effect of combined application of phosphorus and sulphur showed no significant differences in respect of K content in soil after harvest (Table 15). The K content in the post harvest soil ranged from 0.00780% to 0.00970%. The highest K content was observed in $P_{65}S_{40}$ treatment and the minimum value was found in the $P_{35}S_0$ treatment.

4.5.5 Available sulphur

The effect of application of P showed no significant differences in respect of S content of soil after harvest (Table 13). The S content in post harvest soil ranged from 0.001288% to 0.001540% .The highest S content was recorded in P_{35} treatment and the lowest S content was found in the P_0 treatment.

Statistically significant variation was not observed in sulphur content in of the post harvest soil (Table 14). The S content in the post harvest soil ranged from 0.001405% to 0.001570%. The highest P content in was observed in S_{55} treatment and the minimum value was found in the S_{25} treatment.

The effect of combined application of phosphorus and sulphur showed no significant differences in respect of S content of soil after maize harvest (Table 15). The S content of the post harvest soil ranged from 0.00100% to 0.001733%. The highest S content was observed in $P_{65}S_0$ and the minimum value was found in the control treatment (P_0S_0).

Chapter 5
Summary and Conclusion

Chapter 5

SUMMARY AND CONCLUSION

A field experiment was conducted at Sher-e- Bangla Agricultural University Farm, Dhaka during the period from October, 2006 to April, 2007 to study the response of maize to phosphorus and sulphur fertilization. The study included four levels of phophorus, viz., 0, 35, 50 and 65 kg P/ha and four levels of sulphur, viz., 0, 25, 40 and 50 kg S/ha. Triple Super Phosphate and Gypsum were used as the sources of P and S, respectively. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The size of each unit plot was 3m × 3m = 9m^2. The individual plots and the blocks were separated for irrigation and drainage by 1 and 1.5 m canals, respectively. The seeds of maize (BARI Maize-5) were sown on 27 October, 2006 and the crop was harvested on 17 April 2007. Phosphorus and sulphur fertilizers were applied as per treatment combinations. Full doses of potash (MP), Boron and Zinc and one-third of the N (urea) were applied at the time of final land preparation. The rest of the urea was applied in two equal splits on 30 and 60 days after sowing (DAS).

Data were collected in respect of plant height, number of cobs per plant, cob length, circumference of cob, number of grains per cob, 1000-grain weight, shelling percentage, grain yield and stover yield.

Plant heights, grains/cob, 1000-grain weight, stover yield, P, K and S content in maize plant, N, P, K and S uptake by maize plant and organic carbon in post harvest soil were significantly influenced by phosphorus application. Application of 50 kg P/ha resulted tallest plant, highest number of cobs/plant, maximum cob length, maximum grains/cob, highest circumference of cob, highest grain and stover yield, N and S uptake by plant and available P in post harvest soil.

Results showed that the effect of sulphur fertilization was significant on 1000-grain weight, grain and stover yields, P and K content in maize plant, N, P, K and S uptake by maize plant, organic carbon and total N in post harvest soil. Highest values in respect of plant height, cobs/plant, cob length, grains/cob, circumference of grain yield, stover yield, shelling percentage, N content in maize plant, N, K and S uptake by maize plant, organic carbon and available P in post harvest soil were obtained with 40 kg S/ha.

The experimental data also showed that the combined effect of phosphorus and sulphur on various parameters was found positive and significant. Combined application of P and S had significant effect on plant height, number of cobs/plant, cob length, grains/cob, circumference of cob, 1000-grain weight, grain yield, stover yield, N, P, K and S content in maize plant, N, P, K and S uptake by maize plant, organic carbon and total N in post harvest soil. Phosphorus @ 50 kg/ha with sulphur @ 40 kg/ha gave the highest plant height, number of cobs/plant, cob length, grain/cob, circumference of cob, 1000-grain weight, grain yield, stover yield and S uptake by maize plant. Therefore, it can be concluded that the application of 50 kg P and 40 kg S/ha is suitable for the efficient production of maize in the soils of the Modhupur Tract. Application of phosphorus and sulphur at their higher levels showed antagonistic effects on both the concentrations and uptake of phosphorus and sulphur and on the concentration of potassium in maize plant.

Chapter 6
References

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REFERENCES

Ahmed, F. (1994). Maize production techonology (in Bengali). Published by International Fertilizer Development Centre Consultant of Ministry of Agriculture, Bangladesh. pp. 13-15.

Akande, M.O., Adediran, J.A. and Oluwatoyinbo, F.I. (2005). Effects of rock phosphate amended with poultry manure on soil available P and yield of maize and cowpea. Institute of Agricultural Research and Training, Obafemi Awolowo University, P.M.B 5029 Moor Plantation, Ibadan, Nigeria. *African J. Biotech*. **4**(5): 444-448.

Akinrinde, E.A., Bello, O.S. Ayegboyin, K.O. and Iroh, L. (2005). Added benefits of combined organic and mineral phosphate fertilizers applied to maize and melon. Agronomy Department, University of Ibadan, Ibadan, Nigeria. *J. Food, Agric. and Envir.* **3** (3/4): 75-80

Alexandrova, P. and Donov, D. (2003). Nitrogen content and its uptake by maize as influenced by some meteorological elements and fertilization. N. Poushkarov Institute of Soil Science, Sofia 1080, 7, Shosse Bankja str., Bulgaria. *International Agrophysics*. **17**(2): 41-45.

Allen, A.Y. 1976. The effects of sulphur on maize yields in western Kenya. *East Africa Agric. J.* **42**: 313-322.

Alvarez, R., Lencoff, J. and Daniel, P.E. (1987). Accumulation and distribution of sulphur and phosphorus during growth of maize in relation to N fertilizer application. Cent. Radiobiol., Univ. Buenos Aires, Argentina. **8**: 1-2, 77-80; 14.

Araujo, I.B., Furtini Neto, A.E., Resende, A.V., Alves, V.M..C. and Mendes, B.R. 2004. P sources and placement on maize yield and mineral nutrition. *Revista Brasileira de Milho e Sorgo*. **3**(2): 250-264.

Arvind, V., Kanthaliya, P.C. (2004). Crop yields and changes in soil fertility status of a typic ustochrepts under continuous use of fertilizers in maize wheat cropping system. *J. Eco Physiol*. **7**(3/4): 125-128.

Astolfi, S., Zuchi, S., Cesco, S., Varanini, Z. and Pinton, R. (2004). Influence of iron nutrition on sulphur uptake and metabolism in maize (*Zea mays* L.) roots. *Soil Sci. and Plant Nutrition*. **50(7)**: 1079-1083.

Awan, Z.I. and Abbasi, M.K. (2000). Interactive effect of phosphorus and copper on maize growth. *Pakistan J. Agric. Res.* **16**(2): 105-108 .

BARC. 1997. Fertilizer Recommendation Guide. Bangladesh Agricultural Research Council. Farmgate, Dhaka. p. 45.

Barreto, A.C., Serpa, J.E.S. (1988). Effects of phosphorus on maize and bean yields in monoculture and intercrops. EMBRAPA/Centro Nacional de Pesquisa de Coco, 49.000 Aracaju, SE, Brazil.Pesquisa Agropecuaria Brasileira. **23**: 10, 1073-1081; 10 ref.

BBS, 1999. Statistical Pocket book of Bangladesh. Stat. Div. Ministry of Planning. Govt. People's Repub. Bangladesh. Dhaka. p. 186.

BBS. 1995. Statistical Pocket book of Bangladesh. Stat. Div., Ministry of Planning. Govt. People's Repub. Bangladesh. Dhaka. p. 306.

Black, C. A. (1965). Methods of Soil Analysis. Part 2, American Soci. Agro. Inc., Madison, Wisconsin, U.S.A.

Bouyoucos, G. J. (1927). The hydrometer as a new method for the mechanical analysis of soils. *Soil Sci.* **23**: 343-353.

Bremner, J.M. and Mulvaney, C.S.(1982).Total Nitrogen. In: Methods of Soil Analysis. Miller, R.H. and Xeeny, D.R. Am. Soc. Agron. Inc. Madi. Wis. USA. pp. 595-622.

Chowdhury, M.K. and Islam, M.A. (1993). Production and uses of maize (in Bengali). Pub. by On Farm Res. Div. Bangladesh Agril. Res. Inst. Joydebpur, Gazipur. Pp. 1-189.

Cui Yan Shan, DongYi Ting, LiHai Feng, Wang Qin Gren (2004). Effect of elemental sulphur on solubility of soil heavy metals and their uptake by maize. *Environment International.* **30**(3): 323-328.

Debreczeni, K. and Berecz, K. (2000). Effect of nutrient supply and site characteristics on NPK yield of different maize hybrids. *Acta Agronomica Hungarica.* **48**(1): 51-63.

Dhakshinamoorthy, M. and Rani Perumal (2001). Direct, residual and cumulative effects of phosphatic fertilizers on the yield of finger millet, maize and blackgram grown in a cropping system. Tamil Nadu Agricultural University, Coimbatore 641 003, India. *J. Ecobiol.* **13**(1): 9-16.

Dhananjaya, B.C. and Basavaraj, B. (2002). Effect of sulphur application on sulphur fractions in soil as influenced by maize rhizosphere. Department of Soil Science and Agril. Chemistry, College of Agriculture, Dharwad - 580 005, India. Karnataka *J. Agric. Sci.* 2002; **15**(1): 148-150.

Dilip Singh and Singh, S. M. (2000). Response of summer groundnut (*Arachis hypogaea*) and succeeding maize (*Zea mays*) to sulphur and phosphorus fertilization. *Indian Journal of Agricultural Sciences.* **70**(10): 657-660.

FAO, 1999. Production Yearbook. Food and Agricultural Organization of the United Nations. Rome. **52**:62-71.

Fonseca, A.F., Melfi, A.J. and Montes, C.R. (2005). Maize growth and changes in soil fertility after irrigation with treated sewage effluent. II. Soil acidity, exchangeable cations, and sulfur, boron, and heavy metals availability. *Communications in Soil Science and Plant Analysis.* **36**(13/14): 1983-2003.

Gomez, A. K. and Gomez, A. A (1984). Statistical Procedure for Agricultural Research. Intl. Rice Res. Inst., John Wily and Sons. New York, Chickester, Brisbane, Toronto, Singapore. P. 680.

Gordon, R., Gonzalez, A., Franco, J., Gracia, N. Herrera, A. and Raun, W. (1992). Evaluation of dosage and method of application of sulphur and the residual effects on maize cultivars in two localities of Azuero, Panama. *Agronomia Mesoamericana*. **3**: 52-56.

Grant, P. M. and Rowell, A. W. G. 1976. Studies on sulphate fertilizers for Rhodesian crops. Effect of sulfur in fertilizer components on the yield and sulfur status of maize. Rhod. *J. Agric. Res.* **14**: 101-109.

Hammam, G.Y. 1995. Effect of nitrification inhibitor (nitrapyrin) and nitrogen levels on growth and yield of maize (*Zea mays* L.). *Ann. Agril. Sci. Moshtohor*. **33**(2): 495-506.

Hussaini, M.A., Ogunlela, V.B., Ramalan, A.A. and Falaki, A.M. (2001). Growth and development of maize (*Zea mays* L.) in response to different levels of nitrogen, phosphorus and irrigation. *Crop Research Hisar*. **22**(2): 141-149.

Islam, T. M. T. and Kaul, A. K. 1986. Prospect of maize in Bangladesh. FAO/UNDP Publication, Dhaka.

Jackson, M. L. (1973). Soil Chemical Analysis. Prentice Hall Inc., Engle-wood, Cliffs, N.Y.

Jena, D., Jena, M.K., Pattanayak, S.K., Sahu, D. and Mitra, G.N. (2004). Evaluation of compacted phosphate rocks for maize-mustard cropping sequence in a Typic Haplaquept of North Eastern Ghat zone. *J. Indian Soc. Soil Sci.* 2004; **52**(1): 80-84.

Jiang Dong, Hengsdijk, H., Dai Ting Bo., Boer, W., Jing Q. and Cao Wei Xing (2006). Long term effects of manure and inorganic fertilizers on yield and soil fertility for a winter wheat-maize system in Jiangsu, China. **16**(1): 25-32.

Jibrin, J.M., Chude, V.O., Horst, W.J. and Amapu, I.Y. (2002). Effect of cover crops, lime and rock phosphate on maize (*Zea mays* L.) in an acidic soil of Northern Guinea Savanna of Nigeria. National Agricultural Extension and Research Liaison Services, Ahmadu Bello University, Zaria, Nigeria. *J. Agric. and Rural Dept. in the Tropics and Subtropics*. **103**(2): 169-176.

Kale, K.D., Patil, A.S. and Pharande, A.L. (2005). Response of sunflower to application of sources of N and P and their residual effect on maize for fodder in an alfisol. *J. Maharashtra Agric. Univ.* **30**(2): 220-222.

Kang, B. T. and Osiname, O. A. 1976. Sulphur response to maize in Western Nigeria. *Agron. J.* **68**: 333-336.

Kaul, A. K. and Rahman, M. M. 1983. Crop diversification for intensive cropping. Paper presented at First Workshop on National Cropping System Research. BARI. Joydebpur, Gazipur. 10-13:16 p.

Khan, M.A., Abid, M., Hussain, N. and Masood, M.U. (2005). Effect of phosphorous levels on growth and yield of maize (*Zea mays* L.) cultivars under saline conditions. *International J. Agric. and Biol.* **7**(3): 511-514.

Khan, M.J., Khan, M.H., Khattak, R.A. and Jan, M.T. (2006). Response of maize to different levels of sulfur. *Communications in Soil Science and Plant Analysis.* **37**(1/2): 41-51.

Kruczek, A. (2005). Phosphorus utilization from fertilizer and accumulation of mineral components in the initial stage of maize development. *Polish J. Env. Studies.* **14**(4): 467-475.

Kruczek, A. and Szulc, P. (2004). Occurrence of diseases and insects on maize as influenced by phosphorus fertilization. *Progress in Plant Protection.* **44**(2): 873-876.

Kumar, M. and Singh, M. (2003). Effect of nitrogen and phosphorus levels on yield and nutrient uptake in maize (*Zea mays* L.) under rainfed condition of Nagaland. *Crop Research Hisar.* **25**(1): 46-49.

Kumaresan, M., Shanmugasundharam, V.S., Govindasamy, M.,Balasubramaniam, T.N. (2003). Phosphorus balance in maize sunflower cowpea fodder cropping system. *Agric. Sci. Digest.* **23**(1): 65-66.

Leach, K.A. and Hameleers, A. (2001). The effects of a foliar spray containing phosphorus and zinc on the development, composition and yield of forage maize. *Grass and Forage Science.* **56**(3): 311-315.

Li Shao Chang, Hu ChangHao, Gong Jiang and Yang GuanYin (2004). Effects of phosphorus supply on nitrogen and potassium uptake and distribution in maize varieties differing in their phosphorus use efficiency. *Plant Nutrition and Fertilizer Science.* **10**(3): 237-240.

Ling Fan and Silberbush, M. (2002). Response of maize to foliar vs. soil application of nitrogen phosphorus potassium fertilizers. *Israel. J. Plant Nutrition.* **25**(11): 2333-2342.

Liu Cun Hui, Dong Shu Ting and Hu Chang Hao (2001). Effects of sulfur nutrient in high yield summer maize. *J. Shandong Agric. Univ.* **32**(1): 11-16.

Liu Cun Hui, Dong Shu Ting, Hu Chang Hao (2002). Effects of sulfur fertilizer application on mineral element absorption of high yielding summer maize. *J. Maize Sci.* **10**(3): 86.

Liu Ming Qiang, Yu Zhen Rong and Liu Yun Hui (2005) Modelling the relationship between summer maize NPK uptake and yield on the basis of soil fertility indices. *Agricultural Sciences in China.* **4**(10): 774-780.

Lopez, P. A., Paz, P.M., Chacon, L.A. and Guerrero, J.R. (1991). Response of maize (*Zea mays* L.) to the biofertilizer PHS compared to other sources of phosphorus under glasshouse conditions. *Revista Cientifica-UNET.* **5**: 1, 37-43.

Majumdar, B., Venkatesh, M.S., Kumar, K. and Patiram (2002). Effect of nitrogen, sulphur and pig manure application on yields, nutrient uptake and quality parameters of maize-mustard crop rotation and residual nutrient build up in an acidic alfisol of Meghalaya. *J.Hill Res.* **15**(2): 63-70

Manoj Kumar and Singh, M. (2003). Effect of nitrogen and phosphoms levels on yield and nutrient uptake in maize (*Zea mays* L.) under rainfed condition of Nagaland. *Crop Research Hisar.* **25**(1): 46-49.

Martins, A.G., Alvarez V.V.H., Novais, R.F., Galvao, J.C.C. and Silva, A.P. (2005). Effects of the localization of the phosphate fertilizers on the growth of maize plants. *Revista Ceres.* **52**(304): 939-953.

Mehta, Y.K., Shaktawat, M.S. and Singhi, S.M. (2005). Influence of sulphur, phosphorus and farmyard manure on yield attributes and yield of maize (*Zea mays* L.) in southern Rajasthan conditions. *Indian J. Agron.* **50**(3): 203-205.

Nziguheba, G., Merckx, R. and Palm, C.A. (2002). Soil phosphorus dynamics and maize response to different rates of phosphorus fertilizer applied to an Aridisol in western Kenya. *Plant and Soil.* **243**(1): 1-10.

Olsen, S. R., Cole, C. V., Watanable, F. S. and Dean, L. A.(1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U. S. Dept. Agr. Circ. p. 939.

Ortas, I., Kaya, Z. and Cakmak, I. (2001). Influence of arbuscular mycorrhizae inoculation on growth of maize and green pepper plants in phosphorus and zinc deficient soil. Department of Soil Science, The University of Cukurova, Adana, Turkey. Plant nutrition: food security and sustainability of agro ecosystems through basic and applied research. Fourteenth International Plant Nutrition Colloquium, Hannover, Germany. 632-633.

Page, A. L., Miller, R. H. and Keeney, D. R. (1982). Methods of Soil Analysis, Part 2 (2nd Edn.). Amer. Soc. Agron., Inc., Madi., USA.

Pandey, R.N., Girish, B.H. and Brajendra (2002). Influence of sulphur application on dry matter yield and sulphur nutrition of maize (*Zea mays* L.) in major soil orders in India. *Annals of Agricultural Research.* **23**(2): 263-270.

Patel, G J., Patel, G.N., Goyal, S.N. and Patel, B.G. (2000). Effect of phosphorus on the growth and yield of hybrid maize (*Zea mays* L.). *Gujarat Agric. Univ. Res. J.* **26**(1): 59-60

Patel, J R., Thaker, K R., Sadhu, A.C., Patel, P.C. and Parmar, H.P. (1997). Effect of seedrates and nitrogen and phosphorus levels on forage maize (*Zea mays* L.) varieties. *Gujarat Agric. Univ. Res. J.* **23**(1): 1-8.

Patel, K.P., Ramani V.P. and Patel, K.C. (2002). Evaluation of sulphur response in groundnut wheat and maize gram cropping systems in soils of middle Gujarat and Saurashtra Region. *Fertiliser Marketing News.* **33**(4): 7-17.

Pierre, R., Robbles, A., Celado, R., Raun, W.R. and Barreto, H.J. (1990). Maize yield response to sulphur and phosphorus applied under different tillage systems in the Domonican Republic. *Sulphur in Agriculture.* **14**: 16-19.

Piper, C. B. (1942). Soil and Plant Analysis Adellide Univ. Press, Australia.

Prado, R.M., Fernandes, F.M. and Roque, C.G. (2001). Response of maize cultivation to application methods and doses of phosphorus, in maintenance fertilizing. *Revista Brasileira de Ciencia do Solo.* **25**(1): 83-90.

Purushotham, S., Siddaraju, R. and Gopinathan, N. (2002). Response of fodder maize to different levels of N, P, K, and sulphur under irrigation during late rabi. *Current Research University of Agricultural Sciences Bangalore.* **31**(5/6): 87-88.

Ramirez, R. (1980). Nutrition of corn (*Zea mays* L.) in Venezuela. IV. Standard and adequate values of nitrogen, phosphorus, potassium, calcium and magnesium for the interpretation of foliar analysis on corn leaves. *Agronomia-Tropical*. **30**: 1-6, 125-133.

Ramirez, R., Montilla, M. and Zamora, J. (1999). Maize response to ammonium thiosulfate application to a sodic soil. *Interciencia*. **24**(2): 124-126.

Raun, W.R. and Barreto, H.J. (1991). Maize yield response as affected by phosphorus, sulphur and nitrogen as banded applications on a volcanic ash derived tropical soil. *Communications in Soil Sci. and Plant Analysis*. **22** (15-16): 1661-1676.

Reichbuch L. (1987). Effect of long term fertilizer applications with nitrogen and phosphorus on the chemical processes in the soil and the implications on yields of potatoes-wheat-sugarbeet and maize. *Analele Institutului de Cercetari pentru Cereale si Plante Tehnice, Fundulea*. **54**: 255-273.

Sachdev M.S. and Deb D.L. (1990). Nitrogen and sulphur uptake and efficiency in the mustard-moong-maize cropping system. *Fertiliser News*. **35**: 7, 49-55.

Sankaran, K., Savithri, P., Poongothai, S. and Sakthikumaran, S. (2002). Direct and residual effect of sulphur application on maize-greengram cropping system. *Fertiliser Marketing News*. **33**(7): 1-8.

Sankhyan, N.K., Bharat B. and Sharma, P.K. (2001). Effect of phosphorus, mulch and farmyard manure on soil moisture and productivity of maize in mid hills of Himachal Pradesh. *Research on Crops*. **2**(2): 116-119.

Selassie, Y.G., Suwanarit, A., Suwannarat, C. and Sarobol, E. (2003). Equations for estimating phosphorus fertilizer requirements from soil analysis for maize (*Zea mays* L.) grown on Alfisols of Northwestern Ethiopia. *Kasetsart J., Natural Sci.* **37**(3): 284-295.

Setia, R.K., Sharma, K.N. (2005). Effect of long term differential fertilizer application on depth distribution of forms of sulfur and their relationship with sulfur nutrition of wheat under maize wheat sequence. *J. Indian Soil Sci.* **53**(1): 91-96

Sharma, J.P. and Sharma, U.C. (1991) Effect of nitrogen and phosphorus on the yield and severity of turcicum blight of maize in Nagaland. *Indian Phytopathology.* **44**(3): 383-385.

Sharma, R.P., Singh P. and Gupta T.C. (2002) Residual effect of weed management and phosphorus on succeeding fodder maize : a study on N and P concentration and their uptake. *Annals of Agri. Bio. Research.* **7**: 1, 13-16.

Shiluli, M.C., Macharia, C.N. and Kamau, A.W. (2003). Economic analysis of maize yield response to nitrogen and phosphorus in the sub-humid zones of western Kenya. *African Crop Sci J.* **11**(3): 181-187.

Simonete, M.A., Kiehl, J.De. C., Andrade, C.A. and Teixeira, C.F.A. (2003). Effect of sewage sludge in a Ultisol and on growth and nutrition of maize. *Pesquisa Agropecuaria Brasileira.* **38**(10): 1187-1195

Singh, C., Sharma, A.K. and Johri, B.N. (2002). Host genotype determines the impact of soil phosphorus on arbuscular mycorrhizal symbiosis in maize (*Zea mays* L.). *Symbiosis-Rehovot.* **33**(2): 145-164.

Singh, D. and Chhibba, I.M. (1991). Evaluation of some sources of sulphur using maize and wheat as test crops. *J. Indian Soc. Soil Sci.* **39**(3): 514-516

Singh, D. and Singh, S.M. (2000). Response of summer groundnut (*Arachis hypogaea*) and succeeding maize (*Zea mays*) to sulphur and phosphorus fertilization. *Indian J. Agric. Sci.* **70**(10): 657-660.

Sinha, R.B., Sakal, R. and Kumar, S. (1995). Effect of sulphur and phosphorus nutrition of winter maize in calcareous soil. *J. Indian Soc. Soil Sci.* **43** (3): 413-418.

Stanchev, A., Tzolova, V.. Dimitrova, F. and Peneva, N. (2001). Effect of phosphorus and zinc fertilization on the removal of biogenic elements of maize hybrids, grown on calcareous chernozem. I. Removal of phosphorus. *Agrokhimiya Ekologiya.* **36**(4/6): 201-204.

Tagwira, F. (1995). Growth, yield, phosphorus and zinc uptake by maize as affected by lime and phosphate applications*Zimbabwe J. Agri. Res.* **33**(1): 69-82.

Talukder, M.K.H. and Islam, M.S. (1982). Yield responses of maize to different rates of phosphorus and sulphur during the *Kharif* season of Bangladesh. *Bangladesh J. Agril. Res.* **7** (2): 108-113.

Thakur, C. 1980. Scientific crop production. Vol. 1, Food crops. Metropolitan Book Co. New Delhi. pp. 145-185.

Thind, S.S., Chibba, I.M. and Sidhu, A.S. (2003). Evaluation of different soil test methods to predict phosphorus availability to winter maize in alluvial soils. *Annals Agric. Res.* **24**(3): 474-477.

Wang Rong Ping, Wang Yan, Huang Jian Guo (2004). Effects of low phosphorus stress on yield contributing characters of different maize genotypes. *J. Southwest Agric. Univ.* **26**(6): 715-717&722.

Yadav, V.B., Souza, T.J. (1992). Direct and residual effects of ammonium ortho- and polyphosphates with zinc and iron for a maize-blackgram sequence in a Vertisol. *J. Res. Birsa Agric. Univ.* **4**: 1, 5-10.

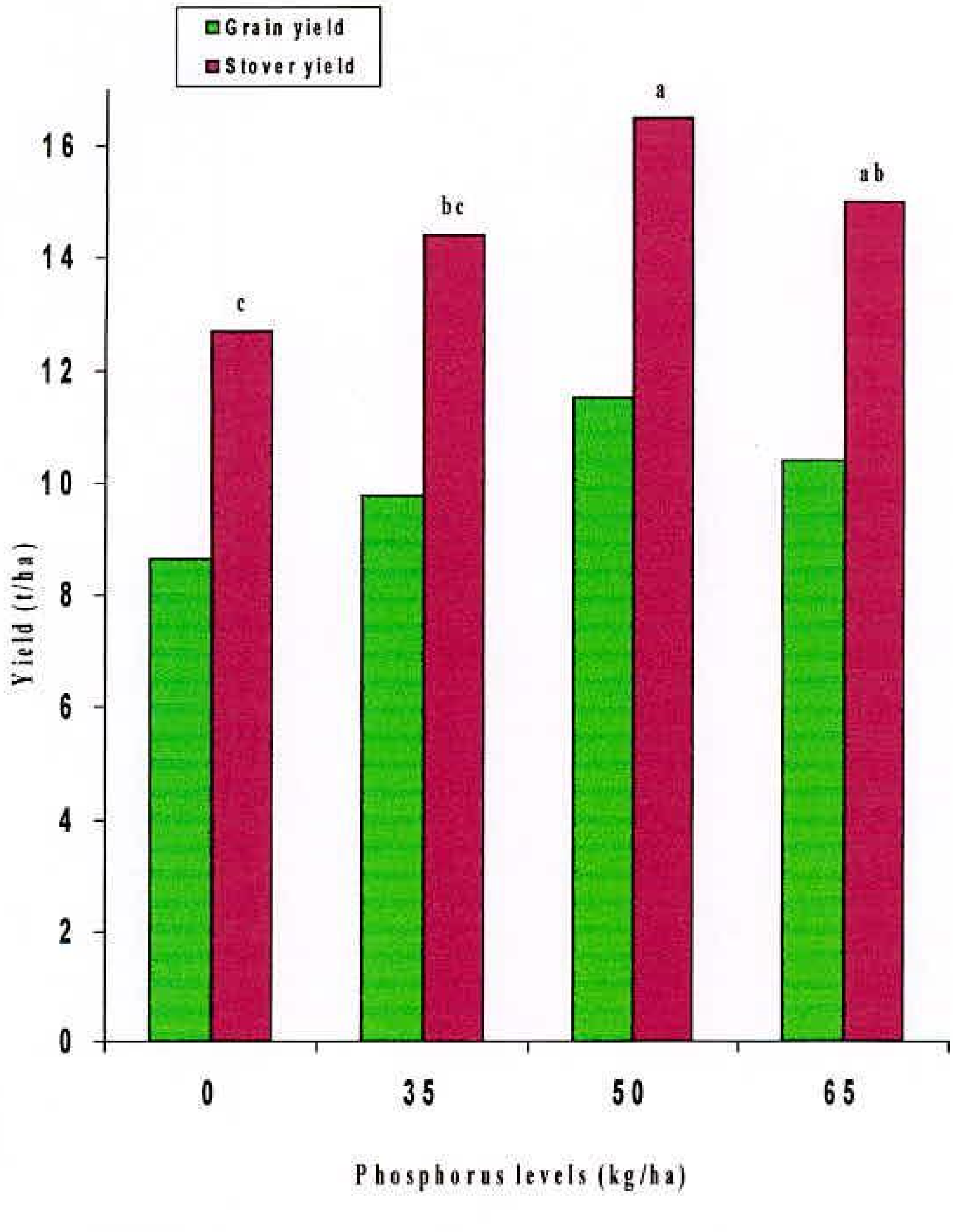
Zhang Li Mei, He Li Yuan, Li Jian Sheng, Xu Shang Zhong (2005). Phosphorus nutrient characteristics of different maize (*Zea mays* L.) inbreeds for tolerance to low-P stress. Agricultural Sciences in China. **4**(4): 281-287.

APPENDICES

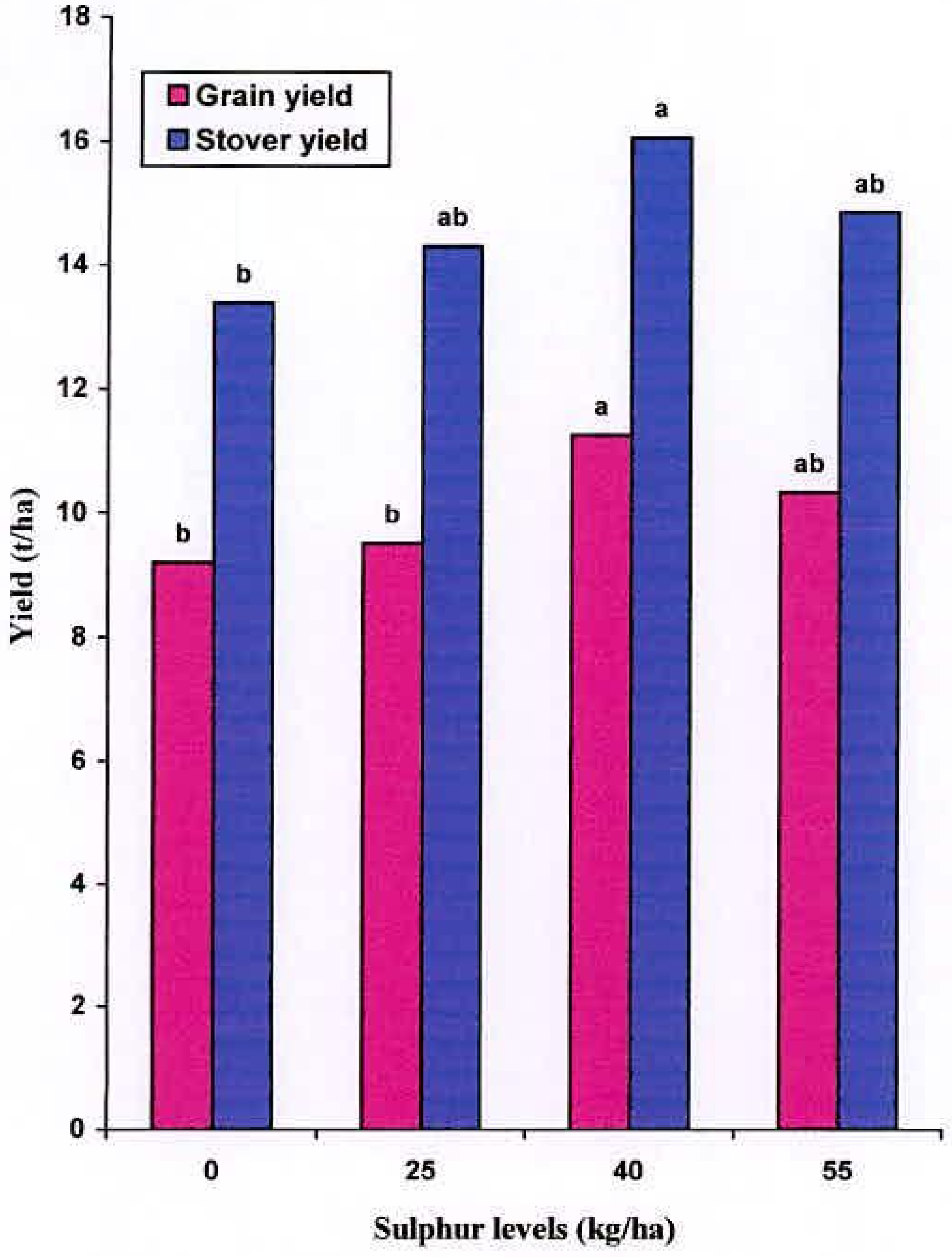
Appendix 1 . Monthly records of meteorological observation at the period of experiment (October, 2006 to April, 2007)

Month	Temperature (Maximum, ^{O}C)	Temperature (Minimum, ^{O}C)	Humidity (%)	Precipitation (mm)
October	31.51	24.13	71.00	168
November	30.20	20.13	68.00	31
December	26.60	13.5	52.7	9
January	25.40	12.93	48.3	7
February	25.30	14.2	55.8	7
March	28.3	17.2	72.30	15
April	31.6	19.5	80.00	56

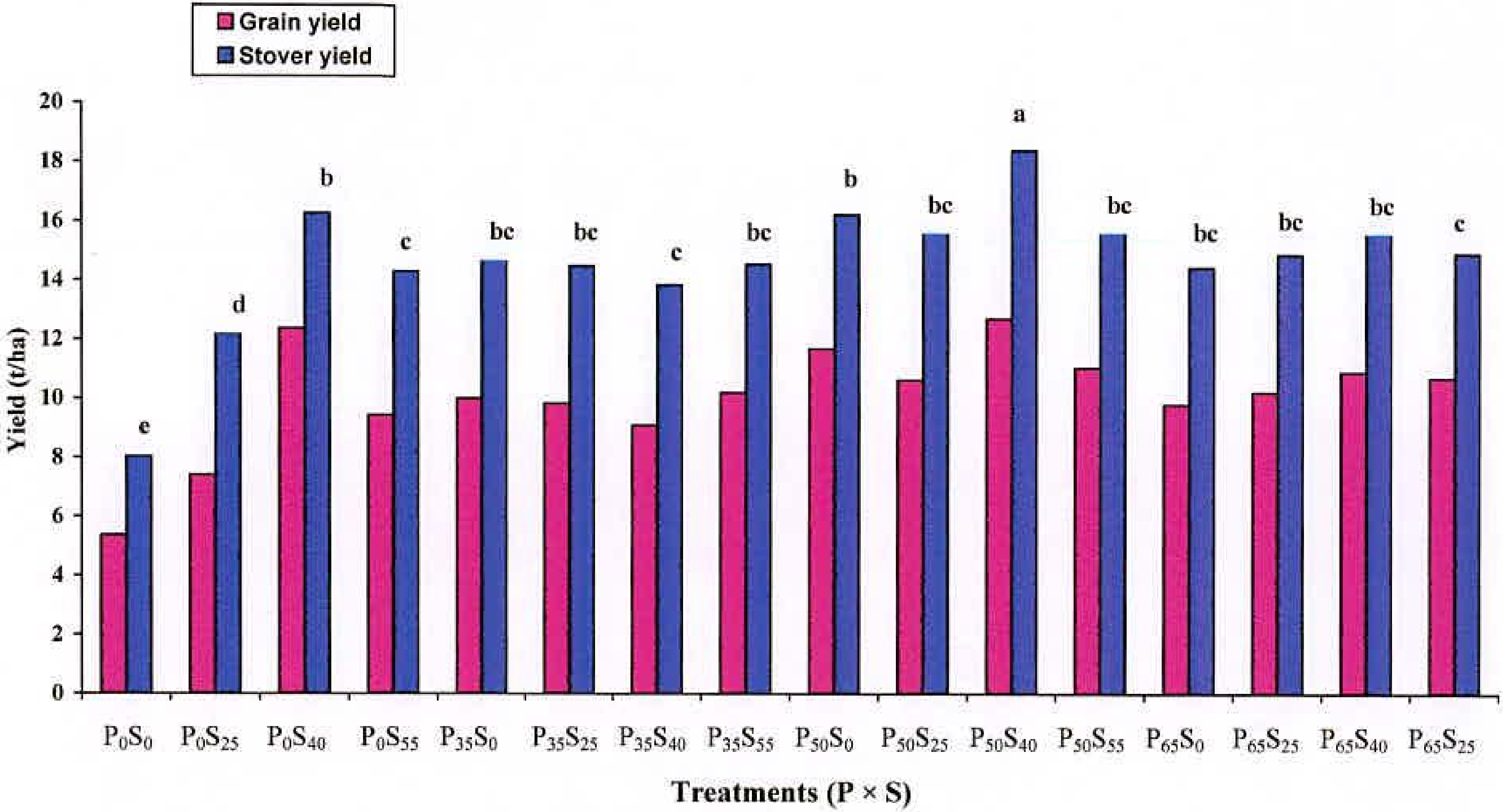
Source : Weather Yard, Bangladesh Metrological department, Dhaka.



Appendix Fig. I. Effect of phosphorus levels on the grain and stover yields of maize.



Appendix Fig. II. Effect of sulphur levels on the grain and stover yields of maize.



Appendix Fig. III. Combined effect of phosphorus and sulphur on the grain and stober yields of maize.