GROWTH AND YIELD OF BARI TOMATO 11 IN RESPONSE TO APPLICATION OF PHOSPHORUS AND SULPHUR

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JUNE, 2018

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A Thesis
Submitted to the Department of Agricultural Chemistry
Sher-e-Bangla Agricultural University, Dhaka
In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE (MS)

IN

AGRICULTURAL CHEMISTRY

SEMESTER: JANUARY- JUNE, 2018

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CERTIFICATE

This is to certify that the thesis entitled **"GROWTH AND YIELD OF BARI TOMATO 11 IN RESPONSE TO APPLICATION OF PHOSPHORUS AND SULPHUR"** submitted to the Department of Agricultural Chemistry, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE (M.S.)** in **AGRICULTURAL CHEMISTRY**, embodies the result of a piece of bonafide research work carried out by **MD. NAZMUL HASAN EVAN**, **Reg. No. 12-04797** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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Dedicated to

My

Beloved Parents

ACKNOWLEDGEMENTS

The author seems it a much privilege to express his enormous sense of gratitude to the almighty Allah for there ever ending blessings for the successful completion of the research work.

The author wishes to express his gratitude and best regards to his respected Supervisor ***Dr. Rokeya Begum, Professor****, Department of Agricultural Chemistry, SAU, Dhaka, Bangladesh for her continuous direction, constructive criticism, encouragement and valuable suggestions in carrying out the research work and preparation of this thesis.*

The author wishes to express his earnest respect, sincere appreciation and enormous indebtedness to his reverend Co-supervisor, ***Dr. Md. Sirajul Islam Khan****, Associate Professor, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, for his scholastic supervision, helpful commentary and unvarying inspiration throughout the research work and preparation of the thesis.*

The author feels to express his heartfelt thanks to the honorable Chairman, ***Dr. Md. Sirajul Islam Khan,*** *Department of Agricultural Chemistry along with all other teachers and staff members of the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, for their co-operation during the period of the study.*

The author feels proud to express his deepest and endless gratitude to all of his course mates and friends to cooperate and help him during taking data from the field and preparation of the thesis. The author wishes to extend his special thanks to his lab mates, class mates and friends for their keen help as well as heartiest co-operation and encouragement.

The author expresses his heartfelt thanks to his beloved parents, Elder Sister and Brother and all other family members for their prayers, encouragement, constant inspiration and moral support for his higher study. May Almighty bless and protect them all.

The Author

GROWTH AND YIELD OF BARI TOMATO 11 IN RESPONSE TO APPLICATION OF PHOSPHORUS AND SULPHUR

ABSTRACT

The present experiment was carried out at the Farm of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from October 2017 to April 2018 to find out the growth and yield of BARI tomato 11 in response to application of phosphorus and sulphur. The experiment was done with four level of phosphorus *viz*. 0, 20, 30, 40 kg P ha^{-1} and four levels of sulphur (*viz*. 0, 10, 15 and 20 kg S ha^{-1}). The experiment was set up in Randomized Complete Block Design (RCBD) with three replications. Data on growth and yield parameters were recorded and analyzed statistically. Results showed that different levels of phosphorus and sulphur significantly influenced all growth and yield contributing characters and yield of tomato. The phosphorus (P) treatment P_2 (30 kg P ha^{-1}) showed the highest number of branch $plant^{-1}$ (5.94), number of flower clusters $plant^{-1}$ (12.35), number of flowers $cluster^{-1}$ (27.49), number of fruits $cluster^{-1}$ (20.69), number of fruits $plant^{-1}$ (255.70), number of fruits $plot^{-1}$ (1023.00), fruit weight $plot^{-1}$ (7.03 kg) and fruit yield ha^{-1} (40.15 t) compared to control treatment P_0 (0 kg P ha^{-1}). The sulphur (S) treatment S_1 (10 kg S ha^{-1}) resulted the the highest number of branch $plant^{-1}$ (6.05), number of flower clusters $plant^{-1}$ (12.75), number of flowers $cluster^{-1}$ (27.13), number of fruits $cluster^{-1}$ (20.23), number of fruits $plant^{-1}$ (253.40), number of fruits $plot^{-1}$ (1014.00), fruit weight $plot^{-1}$ (6.87 kg) and fruit yield ha^{-1} (39.23 t) compared to control treatment S_0 (0 kg S ha^{-1}). The treatment combination of P_2S_1 (30 kg P ha^{-1} and 10 kg S ha^{-1}) performed best in terms of highest number of branch $plant^{-1}$ (6.64), number of flower clusters $plant^{-1}$ (13.03), number of flowers $cluster^{-1}$ (30.07), number of fruits $cluster^{-1}$ (22.10), number of fruits $plant^{-1}$ (284.10), number of fruits $plot^{-1}$ (1136.00), fruit weight $plot^{-1}$ (7.63 kg) and fruit yield ha^{-1} (43.59 t). Different doses of P and S nutrients showed significant variation on N, P and S concentration in post harvest plant shoot and root but K concentration in shoot and root was not significant. The treatment combination of P_3S_3 performed as for N, P, K and S concentration in plant shoot and root compared to control.

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ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
BCSRI	=	Bangladesh Council of Scientific Research Institute
cm	=	Centimeter
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
DMRT	=	Duncan’s Multiple Range Test
et al.,	=	And others
e.g.	=	exempli gratia (L), for example
etc.	=	Etcetera
FAO	=	Food and Agricultural Organization
g	=	Gram (s)
i.e.	=	id est (L), that is
Kg	=	Kilogram (s)
LSD	=	Least Significant Difference
m^2	=	Meter squares
ml	=	MiliLitre
M.S.	=	Master of Science
No.	=	Number
SAU	=	Sher-e-Bangla Agricultural University
var.	=	Variety
^oC	=	Degree Celsius
%	=	Percentage
NaOH	=	Sodium hydroxide
GM	=	Geometric mean
mg	=	Miligram
P	=	Phosphorus
K	=	Potassium
Ca	=	Calcium
L	=	Litre
µg	=	Microgram

CHAPTER I

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill or *Solanum lycopersicum*) is one of the most popular and nutritious vegetable crops in Bangladesh which belongs to the family Solanaceae. It has taproot and growth habit of the plant is determinate, semi-determinate and indeterminate (Reddy *et al*., 2013). It originated in tropical America (Salunkhe *et al*., 1987), mainly in the region of the Andes Mountain in Peru and Bolivia (McCollum, 1992). It is widely grown in every parts of the world. It ranks next to potato in Bangladesh and tops the list of canned vegetable (BBS. 2016). It is an important cash generating crop for small scale farmers and also provides employment opportunities in production and processing industries (Meena *et al*., 2015). In the year 2015-16, the total production of tomato was 67000 metric tons which is produced in 368 acres of land with as average yield 5.45 t/acre (BBS, 2017).

Tomato's food value is very rich because of higher contents of vitamin A, B and C including calcium and carotene (Bose and Som, 1990). It also possesses medicinal value. It is much popular as raw salad. It is also used as vegetable or as processed food items such as sauce, soup, juice, ketchup, pickles, paste, puree, powder, jam, and jelly. Excellent nutritional and processing qualities have made tomato very much demandable in both domestic and foreign markets.

Soil and climate condition in winter season of Bangladesh are suitable for tomato cultivation, yet the average yield of tomato is low, 10.26 t ha^{-1} (BBS, 2015) as compared to other tomato producing countries such as India (15.04 t ha^{-1}), Japan (52.8 t ha^{-1}), USA (62.2 t ha^{-1}), China (30.4 t ha^{-1}) and Egypt (34.0 t ha^{-1}) (FAO, 2002). Lower yield of tomato in Bangladesh may be attributed to unavailability of quality seeds of improved verities, improper use of fertilizer, disease, pest, and irrigation management. Out of these, proper fertilizer management practices and use of quality seed may improve yield level greatly (Ali *et al.*, 1994).

As soils of Bangladesh are deficient in phosphorus, it is necessary to apply this nutrient element for satisfactory growth and yield of tomato. High level of phosphorus is essential for rapid root development, good utilization of water and other nutrients. Application of phosphorus fertilizers has shown good yield responses for different crops across different locations, indicating low phosphorus status of the soils (Yohannes, 1994). Application of phosphorus is an important nutrient for tomato plant growth and development, a deficiency of P leads to reduced growth and reduced yields (Hochmuth *et al.*, 2009). Tomatoes have the greatest demand for phosphorus at the early stages of development (Csizinszky, 2005). Phosphorus has pronounced effect on flower cluster production and the number of flower that increases the yield (Zhang et al., 2007; Sarker, 2006; Solaiman and Rabbani, 2006; Karim, 2005). P plays a vital role on root growth and development and is important constituent of nucleoproteins and nucleic acids plant metabolism. Also, believed that maximum height, maximum number of fruits, size and weight achieved through P application and promotes root formation (Parihar and Tripathi, 2003).

Sulphur is a plant nutrient with a crop requirement similar to that of phosphorus. Sulphur is known as the fourth major plant nutrient (Gowswamy, 1986). It is essential constituent of sulphur containing amino acids cystine, cysteine and methionine and plays vital role in regulating the metabolic and enzymatic process including photosynthesis, respiration and symbiotic N fixation, besides being responsible for the synthesis of vitamins such as biotine, thiamine, vitamin B and certain coenzymes (Chadha, 2003, Kumar and Singh, 2009).

It has been observed when sulphur is present in critical amount in soil (Less than 10 ppm), the plant growth, quality and total production of crop is adversely affected (Jones et al., 1972). Sulphur application in vegetable crops have been found to improve quality attributes, protein content, oils and vitamins (Dhar et al., 1999 and Sriramchandra Sekharan, 2009). Sulphur also helps in improving the nutrient content and uptake of nutrients in legume crops (Singh and Singh. 1992). S is a constituent of secondary compounds *viz*., allin, cycloallin and thiopropanol which not only influence the taste, pungency and medicinal properties of vegetable crops but also induce resistance against pests and diseases (Tabatabai, 2001).

Numerous research works have been carried out on fertilizer requirements and the effect of plant nutrients like P and S on growth and yield of tomato in developed countries but information on systematic research in this context in Bangladesh is limited. Therefore, the present research was undertaken to find out the optimum level of phosphorus (P) and sulphur (P) for maximizing growth, yield and yield contributing characters in tomato.

1. To investigate the effect of phosphorus on growth, yield and quality of BARI tomato 11
2. To find out the effect of sulphur on growth, yield and quality of BARI tomato 11
3. To find out the suitable combination of phosphorus and sulphur concentration for higher yield of BARI tomato 11

CHAPTER II

REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum*) is one of the most of the important vegetable in Bangladesh. It is evident that phosphorus (P) and sulphur (S) has great influence on growth and yield of tomato. Numerous investigators in various parts of the world have investigated the response of tomato to different levels of P and S for its successful cultivation. This chapter deals with a brief and relevant review of many researchers in relation to the effects of P and S on the growth and yield of tomato in Bangladesh perspective and also in the other parts of the world. The related review of literature was presented under the following heading and sub headings:

2.1 Effect of phosphorus (P)

Dhiman *et al*. (2018) conducted an investigation entitled "Effect of nitrogen and phosphorus on tomato (*Solanum lycopersicum* L.) grown under polyhouse condition". The treatments consisted of T_1: Control, T_2: 100% Nitrogen, T_3: 100% Phosphorus, T_4: 75% Nitrogen, T_5: 75% Phosphorus, T_6: 100% Nitrogen + 75% Phosphorus, T_7: 75% Nitrogen + 100% Phosphorus. The minimum days to 50 per cent flowering and days to first picking were recorded with the combined application of 100 per cent Nitrogen and 75 per cent Phosphorus. Maximum number of flowers cluster^{-1}, number of fruits cluster^{-1}, plant height, harvest index, number of fruits plant^{-1} and fruit yield hectare^{-1} content were recorded with the combined application of 100 percent Nitrogen + 75 per cent Phosphorus. Whereas, maximum harvest duration, fruit length, fruit diameter and average fruit weight, were recorded with the conjoint application of 75 percent Nitrogen + 100 percent Phosphorus. These results suggested that the optimum production of tomato can be obtained with integrated application of 100 percent Nitrogen + 75 percent Phosphorus.

Martins *et al*. (2017) aimed to evaluate the effect of P on tomato seedling and fruit production of Paronset hybrid. Six treatments (0, 15, 30, 45, 60 and 75mg L^{-1}P) were evaluated. Monoammonium phosphate (MAP) was used as P source, in addition to coconut fiber substrate. A linear increase was obtained for leaf area, seedling height, shoot and root fresh matter at 75mg P L^{-1}. However, yield and fruits characteristics were not affected by increasing P doses on seedlings.

Zhu and Ozores-Hampton (2017) found that phosphorous (P) has a significant role in root growth, fruit and seed development, and plant disease resistance. The experiment was conducted in 2014 and 2015 with soils containing 13 to 15 mg kg^{-1} of P extracted by ammonium-bicarbonate-iethylene-triamine-penta-acetic acid (AB-DTPA) to evaluate the impact of different P rates on leaf tissue P concentration (LTPC), plant growth, biomass accumulation, fruit yield, and postharvest quality of tomato (*Solanum lycopersicum* L.) grown on a calcareous soil. Phosphorus fertilizers were applied at rates of 0, 29, 49, 78, 98, and 118 kg ha^{-1} of P before laying polyethylene mulch. Plant height, stem diameter, and leaf chlorophyll content at 30 days after transplanting (DAT) were significantly affected by P rates in 2015, but not in 2014. At the first and second combined harvest, the extra large fruit yield was unaffected in 2014, but predictedby a quadratic-plateau model with a critical rate of 75 kg ha^{-1} in 2015. The total season marketable yields (TSMY) and postharvest qualities were not significantly affected by P rates in either year. Phosphorous rate of 75 kg ha^{-1} was sufficient to grow a tomato crop during the winter season in calcareous soils with 13–15 mg·kg^{-1} of AB-DTPA extractable P.

Habibzadeh and Moosavi (2014) conducted an experiment with four phosphorus levels: 2, 5, 10, and 15 mg P kg^{-1} soil possessed phosphorus fertilization treatments and also with arranged inoculations with two mycorrhizal fungal species (*Glomus mosseae*, *Glomus intraradices* and un-inoculated plants). Results showed that colonization of *G. mosseae* and *G.*

intraradices, with 51.36 and 42.94% had the most values at the 2 mg P kg^{-1} soil. Different levels of phosphorus × mycorrhiza interaction showed that G. mosseae had the most leaf phosphorus (414.67 mg/100g of leaf dry weight), leaf area (99 cm^2) and root volume (1.77 cm^3) at the 15 mg P kg^{-1} soil. Leaf phosphorus, above and under-ground fresh weight, shoot height, leaf area, root volume, root length and number of leaves had positive correlation coefficients with above-ground dry matter.

Etissa *et al*. (2013) conducted an experiment with the objectives of evaluating effect of N and P fertilizer applications on growth and yield, and determining optimal requirements for tomato. The treatments consisted of four rates of nitrogen (0, 50, 100 and 150 kg N ha^{-1}) and four rates of P (0, 46, 92 and 138 kg ha^{-1}) under furrow irrigated and rainfed experiment. Maximum fruit yield was estimated from regression lines of applying 105 kg N ha^{-1} and 85 kg P ha^{-1} for furrow irrigated experiment (continuously cultivated field). However, the highest fruit yield was from application of 40 kg N ha^{-1} and P 10 kg ha^{-1} for the rainfed experiment (relatively fertile field). Thus, results of both experiments were averaged to propose on farm verification of N and P requirement of tomato, N 73 kg ha^{-1} and P 48 kg ha^{-1}.

Kumar *et al.* (2013) carried out an experiment to study the effect of nitrogen, phosphorus and potassium fertilizers on the growth, yield and quality of tomato *var*. Azad T-6. Tomato plants were fertilized with different rates of chemical fertilizers i.e. two doses of nitrogen fertilizers N_1 and N_2 (120 and 180 kg/ha), single dose of phosphorus P_1 (80 kg/ha) and potassium K_1 (75 kg/ha). The highest plant height, branch length, the maximum number of primary and secondary branches, number of flowers and fruits/plant as well as the greatest fruit size, fruit yield/plant and fruit yield/ha were obtained from the application of the recommended dose of nutrients *viz*., 120 kg N +80 kg P +75 kg K/ha. The results revealed that significantly the highest plant height higher yield and yield attributing characters were recorded with the application of 100% NPK i.e. 180 kg N/ha along with 80 kg P/ha and 75 kg K/ha.

Rahaman *et al*. (2011) carried out a pot experiment to study the effect of different levels of phosphorus (0, 40, 60 and 80 kg ha^{-1}) on growth and yield of three tomato genotypes (CLN-2026, BINA tomato-4 and BINA tomato-5). Results revealed that morphological growth, yield contributing characters and fruit yield were significantly influenced by different levels of phosphorus. Plant height, branch number, leaf number, flower and fruit cluster number and fruit number $plant^{-1}$ increased with increasing phosphorus levels up to 80 kg ha^{-1}, but from the economic point of view, 60 kg ha^{-1} was the best for the fruit yield.

Gad and Kandil (2010) carried out an experiment to evaluate the effect of cobalt and different sources of phosphorus fertilizers on the growth, yield quantity and quality of tomato. Treatments were arranged in descending order as: Mono super phosphate (MSP) > Triple super phosphate (TSP) > Rock phosphate (RP). Mono super phosphate (MSP) had superior effect on all growth parameters of tomato shoots and roots yield quantity and quality as well as mineral nutrient constituents of tomato fruits compared with other phosphorus sources. Rock phosphate (RP) treatment gave the lowest values of tomato growth, yield, chemical constituents and mineral composition of tomato fruits. Cobalt addition enhanced all parameters of tomato growth and yield with all sources of phosphorus fertilizers especially with mono superphosphate.

Adebooye *et al.* (2006) conducted an experiment to evaluate how tomato fruit qualities were affected by phosphorus (P) nutrition. The P treatments were 0, 13.2, 26.4, 39.6 and 52.8 kg P/ha using single superphosphate fertilizer (18% P), while the three tomato cultivars used were Ibadan Local, Roma VF and NHLe 158-13. At 26.4 kg P/ha, significantly higher fruit diameter and fruit yields were obtained. Except for the moisture content and ether extract, the P level had significant effects on the pH, total soluble solids (TSS), lycopene, ascorbic acid, crude fibre and crude protein content of tomato fruits with the optimum values recorded at 26.4 kg P/ha. The study established that 26.4 kg P/ha was the optimum P level for the tomato cultivars used in this study.

Shukla *et al.* (2006) conducted an experiment in farmer's field to study the effects of inorganic and organic fertilizers on the performance of tomato (*Solanum lycopersicum*). The application of recommended rates of N, P and K (100, 75 and 55 kg/ha, respectively) with farmyard manure and vermicompost (250 and 12.5 quintal/ha, respectively) was superior in terms of yield per plant, yield/ha, number of fruits per plant, average fruit weight, number of fruits per cluster, and TSS [total soluble solids] content. The combined effects of N, P, K, farmyard manure and vermicompost on harvest duration and pericarp thickness were not significant. Vermicompost with N, P and K induced early flowering, whereas early picking was obtained with the application of vermicompost and P.

Kuchanwar *et al.* (2005) conducted a field experiment with tomato *(Lycopersicon esculentum)* as a test crop. The effects of P application at three levels (30, 60 and 90 kg P_2O_5 ha^{-1}), two levels of S (30 and 60 kg S ha^{-1}) and two levels of Fe (20 and 40 kg Fe ha^{-1}) and their combinations were investigated. The highest content of N, P, K, S and Fe (1.34, 0.74, 1.78, 0.18, 5.89 in fruits and 0.75, 0.70, 3.61 0.32, 3.55 in plants, respectively) was recorded with the application of 60 kg P_2O_5 + 30 kg S + 40 kg Fe ha^{-1}. The highest P and S was recorded with the application of 90 kg P_2O_5+ 60 kg S + 40 kg Fe ha^{-1} and 30 kg P2O5 + 60 kg S + 40 kg Fe ha^{-1}, respectively. The total uptake of N, P, K, S and Fe was maximum (53.04, 21.22, 153.63, 10.69 kg ha^{-1}, 249.59 g ha^{-1}, respectively) with the application of 60 kg P2O5 + 30 kg S + 40 kg Fe ha^{-1}.

Long-Jing and Jing-Quan (2005) evaluated the effects of phosphate levels (0, 0.165, 0.660, 2.640 mmol phosphate/litre) on growth and photosynthesis of 4-leaf tomato plants. P at 0 and 0.165 mmol/litre significantly inhibited plant growth, reduced net photosynthetic rate, stomatal conductance, and photochemical efficiency of photosystem II, and increased intercellular CO_2 concentration.

Groot *et.al* (2004) evaluated the effects of N and P rates on the growth of tomato (cv. Capita). P was applied at 70, 120, 170, 220, 270 and 320 mg g^{-1} day^{-1}; N was supplied at the same concentrations, in addition to 370 mg g^{-1} day^{-1}. The relative growth rate increased sharply with increasing plant P concentration, then leveled off. At mild P and N limitation, leaf area ratio and relative growth rate were more important than net assimilation rate (NAR) in explaining the change in RGR, whereas under severe P and N limitation, NAR was more important. The reduction in N and P supply increased dry matter partitioning to roots. This correlation between dry matter partitioning to roots and leaf N concentration was linear.

Sun *et al.* (2004) investigated the effects of N, P and K fertilizers on the growth of tomato seedlings on a sawdust: vermiculite: fly ash (6:2:2) substrate were studied. Seedling growth was highly affected by N, P, and N × P interaction. The values of growth parameters (stem height and diameter, fresh weight, dry weight, leaf area, and good seedling index) increased linearly with the increase in the rates of N and P. The highest values of the aforementioned parameters were obtained with 2.4 kg $CO(NH_2)_2$ + 29.5 kg $Ca(H_2PO_4)_2.H_2O$ + $CaSO_4.H_2O$. N × P interaction also enhanced seedling growth, but the effects of P on seedling growth were dependent on the N rate. Seedling growth was adversely affected by P at a low N rate, but was enhanced by P at a high N rate.

Chandra *et al.* (2003) concluded the effects of N: P: K rate (200:100:150, 350:200:250 or 500:300:350 kg/ha) on the performance of 4 indeterminate tomato hybrids (Rakshita, Karnataka, Naveen and Sun 7611) in a multi-span greenhouse during 2000-2001 and 2001-2002 Among the fertilizer levels, N:P:K at 350:200:250 kg/ha was superior in terms of fruit diameter, average fruit weight, yield, gross income and benefit:cost ratio. The number of fruits per plant increased with the increase in the rate of NPK. The quality parameters were not significantly affected by the NPK level in both years.

Groot *et al.* (2003) conducted an experiment with varied N or P supply, in order to unravel the effects of N and P limitation on growth of young tomato plants *(Lycopersicon esculentum* Mill.). Relative growth rate (RGR) initially increased sharply with increasing plant P concentration but leveled off at higher plant P concentrations. The relationship of RGR with organic leaf N and P showed the same shape as with total N and P concentrations, respectively. Experimental results suggest that the decrease in N concentration with increasing P limitation may be mediated by a decrease in leaf cytokinin levels and is less likely due to decreased energy availability at low P conditions.

Duraisami and Mani (2002) concluded that the optimum levels of N, P and K were necessary for yield maximization of rainfed tomato and for sustained soil fertility. Treatments comprised of 4 rates of N (0, 40, 80 and 120 kg/ha), 3 rates of P_2O_5 (0, 40 and 80 kg/ha) and 3 rates of K_2O (0, 40 and 80 kg/ha) in all possible combinations. All treatments recorded higher crop yield compared to the control, with 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha recording the highest yield (20.5 t/ha). TSS had an inverse relationship with N rates but increased with increasing P and K. The treatments had no significant effects on the acidity of the fruits. Soil N was highest with application of 80 kg N and 40 kg P_2O_5/ha. The available soil P varied from 9.7 to 10.9, 10.4 to 10.6 and 10.4 to 10.8 kg/ha with N, P_2O_5 and K_2O application, respectively, with the treatments having no marked effects on the available soil P.

Poulton *et al.* (2002) evaluated that mycorrhizal infection and high soil P conditions improved several vegetative (leaf area, days until first flower and leaf P concentration) and reproductive traits (total flower production, fruit mass, seed number and pollen production per plant, and mean pollen production per flower) in tomato.

Begum *et al.* (2000) conducted a field experiment in the rabi (dry) season to study the effects of irrigation and P fertilizer application on the yield, total water use, and water use efficiency of tomato (cv. Roma VF). Five irrigation levels and four P application rates were used. In the individual effects of irrigation and P application, the yield was significantly high in the three and four irrigations and at 120 kg P_2O_5 ha^{-1}. The treatment with three irrigations along with P application at 120 kg P_2O_5 ha^{-1} was the best combination for the sustainable tomato cultivation (yield of 38.70 Mg ha^{-1} with the maximum net benefit) in shallow red-brown terrace soils of Bangladesh.

Dhinakaran and Savithri (1997) reported the effect of phosphorus applied at 100 kg P2O5/ha significantly increased the yield of tomatoes. Phosphorus content and phosphorus uptake of tomato fruit increased with increased with increased application of phosphorus.

Pandey *et al.* (1996) conducted a fertilizer trial on tomato cultivars Acc-99 Sweet- 72 to investigate the effect of nitrogen and phosphorus in Jabalpur, India. Using phosphorus at 0, 40, and 80 kg/ha, they conducted that the fruit yield increased as phosphorus rate increased up to 80 kg/ha.

2.2 Effect of sulphur (S)

Orman and Kaplan (2017) conducted an experiment and evaluated the effects of elemental sulphur and farmyard manure on agronomic biofortification within the parameters of N, P, S and N:S ratio in green bean (*Phaselous vulgaris* L.). Sulphur 0 (S_0), 50 (S_1), 100 (S_2), 150 (S_3), 200 (S_4), 400 (S_5) mg kg^{-1} and farmyard manure 0 (FYM_0), 3 (FYM_1) t ha^{-1} were applied. The soil pH was decreased while EC was increased by the applications of S and FYM. The P concentration of shoot was increased by S with FYM. While the dry weight and S concentration of shoot were increased, N concentration was slightly decreased by S, alone. The N:S ratio decreased from 23.76 in S0FYM0 to 15.93 in S5FYM1. All results indicate that sulphur applications in S_1 and S_2 levels with farmyard manure can be sufficient for growing bean in the soil.

Muthanna *et al*. (2017) carried out an investigation to study the effect of boron and sulphur application on plant morphology and yield of potato during 2015-16 and 2016-17. Out of thirteen treatments one control, one recommended dose of fertilizers (N/P/K: 150/80/120 kg ha^{-1}) and eleven treatment combinations along with recommended dose of fertilizers (RDF) including 3 doses of boron (1 kg, 2 kg and 3 kg); 2 doses of sulphur (30 kg and 40 kg) and their combinations (1 kg boron + 30 kg sulphur, 2 kg boron + 30 kg sulphur, 3 kg boron + 30 kg sulphur, 1 kg boron + 40 kg sulphur, 2 kg boron + 40 kg sulphur and 3 kg boron + 40 kg sulphur) were applied. The study indicated that plant morphology and yield of potato plant were significantly influenced by boron and sulphur application. The maximum plant height and yield of marketable tubers (17.99 t ha^{-1} and 27.00 t ha^{-1}) were recorded in the plants treated with RDF + 2 kg B + 40 kg S during both year of investigation. RDF + 2 kg B + 40 kg S was also found statistically at par with the maximum values under characters *viz*., stem diameter and number of marketable tubers/hill.

Magray *et al*. (2017) conducted the study to examine the influence of sulphur and potassium applications on yield, uptake and economics of garlic. Sulphur (S) was tested at rates of 0,15, 30, and 45 kg ha^{-1} in combination with potassium (K) applied at rates of 0, 50, 75, and 100 kg ha^{-1}. Increased rate of S and K applications enhanced the yield, uptake and improved economics of production of garlic. Combined application of sulphur @45 kg ha^{-1} and potassium @ 100 kg ha^{-1} recorded significantly maximum values of total bulb yield (244.03 q ha^{-1}) and total marketable yield (220.96) but slightly lower value of uptake of nitrogen (105.29 kg ha^{-1}), Phosphorus (30.84 kg ha^{-1}), potassium (83.90 kg ha^{-1}) and sulphur (38.73kg ha^{-1}).

Staugaitis *et al*. (2017) conducted five years experiment in wheat to establish how different foliar fertilizers affect spring wheat when the optimum nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) rates had been applied during the main fertilisation. It was found that Ammonium sulphate (15.0 kg ha^{-1}) and urea (6.7 kg ha^{-1}) increased grain yield. It was also indicated that the foliar fertilizers used did not increase grain and straw yield significantly.

Silva *et al*. (2014) arranged the experiment with 6 doses of S (0, 20, 40, 60, 80 and 100 mg kg^{-1}) in the form of agricultural gypsum in tomato plant cv. Abiru variety. The fruits were harvested, washed and weighed and the shoots were cropped, weighed and analyzed in relation to levels of carbon, nitrogen and sulfur. The tomato fruit production increased under sulfur doses and highest from 80 mg kg^{-1}, obtaining a 23 to 34% raise. The dry mass of the shoot, content and accumulation increased under the application of sulfur doses on the soil.

Devi *et al*. (2012) studied the effect of sulphur and boron fertilization on yield, quality and nutrient uptake by soybean under upland condition. The study revealed that yield attributing characters like number of branches per plant, branch spread, pods per plant and 100 seed weight and yield were increased with the application of sulphur and boron as compare to control. The overall result revealed that application of 30 kg sulphur per hectare was found to be the optimum levels of sulphur for obtaining maximum yield attributes, yield, and total uptake of sulphur of soybean under upland condition as compare to other levels of sulphur.

Orman and Huseyin (2012) conducted a pot experiment study to evaluate the effects of sulphur (S) and zinc (Zn) on straw and grain dry weight of wheat grown in a calcareous clay loam soil. Sulphur was applied at 0, 10, 50, 250 mg S kg^{-1} (as $CaSO_4.2H_2O$) and zinc at 0, 5 mg Zn kg^{-1} (as $ZnSO_4.7H_2O$) to the soil. The straw S concentration increased by sulphur alone. In the 250 mg S kg^{-1} application to soil, the straw S concentration increased by 28.13% when compared with 0 mg S kg^{-1} treatment. The straw dry weight was significantly affected by sulphur alone and it increased from 2.53 to 3.86%. The results suggest that application of sulphur and zinc could be a good approach for the nutrition of wheat plants.

Saeed and Ahmad (2009) carried out this study to observe the effects of organic mulch with and without gypsum on vegetative growth and reproductive yield of tomato plant (*Lycopersicon esculentum* Mill. cv. F1 Avinash) under control (non-saline) and saline rhizosphere. Data with reference to plant height, fresh and dry vegetative biomass, number of flower and fruit cluster/plant, number of flower and fruit/cluster, number and weight of fruit/plant and circumference of fruit showed comparatively higher growth at all the parameters in T_4 (mixture of mulch and gypsum) followed by T_3 (gypsum alone), T_2 (mulch alone) and T_1 (control without mulch or gypsum) under saline as well as non-saline conditions. Results suggest that application of organic mulches with or without gypsum to soil being irrigated with saline water increases the yield by reducing salinity hazards which could be quantified on growth of tomato plant.

Zelená *et al*. (2009) investigated the effects of different sulphur (S) fertilizers (ammonium, sodium, potassium and calcium sulphates) in combination with nitrogen (N) on plant growth, yield and quality of tomato fruits in two dwarf cultivars Proton and Sejk. Single N, applied as ammonium nitrate, stimulated growth of plants and significantly increased yield of fruits, but did not change content of lycopene as well as colour parameters and decreased significantly S content in fruits. All S fertilizers significantly increased S and lycopene content in fruits (up to 39% in cv. Sejk and 92% in cv. Proton) and positively influenced colour of tomato. The earlier cv. Sejk responded better to S supply than cv. Proton, which showed a negative yield effect especially on variants where higher S doses were applied.

Vaiyapuri et al. (2009) conducted a study in soybean with S application and found that uptake of sulphur, boron and protein content of soybean were improved considerably due to increasing rates of sulphur upto 30 kg ha-1 over lower levels.

Kumawat et al. (2009) observed that transpiration rate and leaf osmotic potential in fenugreek increased significantly with increasing levels of sulphur application upto 40 kg ha^{-1}, but further application of sulphur could not influenced the above parameters.

Chaurasia *et al*. (2009) compared the effect of different levels of sulphur *viz*., 0, 10, 20, 30 and 40 kg ha^{-1} on yield and quality of soybean. Results showed that soybean responded significantly in terms of yield and quality upto 30 kg S ha^{-1} through SSP. Whereas, the treatment of 40 kg S ha^{-1} gave significantly higher uptake of N, P, K and S and increased the availability of these nutrients in the soil.

Santos *et al*. (2007) conducted two field studies to determine the effect of S fertilization on tomato *(Lycopersicon esculentum* Mill.) yield and foliar S concentration. The soil had very low S content (<30 ppm) and 1.5% organic matter. Fertilizer sources were: 1) ammonium nitrate (AN; 34% N) at a rate of 300 lb/acre of N; 2) AN + potassium sulfate (PS; 23% S and 55% K> at rates of 300 + 343 lb/acre of N and S: 3) ammonium sulfate nitrate (ASN; 26% N and

14% S) at a rate of 300 + 343 lb/acre of N and S: and 4) Non-treated control. Plots treated with either rate of AN or non-treated had the lowest foliar S concentration, ranging between 0.55% and 0.53%. However, plots treated with S-containing fertilizers increased foliar S concentration when compared with the non-treated control and AN-treated tomatoes. Average S concentration was about 0.74%, which was 40% higher than the concentration in non-treated control plots. There were no significant marketable yield differences in plots treated with either AN + PS or ASN. Average marketable yield ranged between 27.5 and 28.2 ton/acre in the S-treated plots. In contrast, average yield in the AN-treated plots was 18.7 ton/acre, which was 44% and 42% less than the yields in the AN + PS and ASN-treated plots.

Chhipa (2005) observed a significant increased in chlorophyll content (1.340 and 1.360 mg/g), protein content in curd (2.71 and 2.68%), S content (1.21 and 1.19%) and Zn content (48.37 and 49.15 ppm) with the application of 40 kg S ha^{-1} and 4 kg Zn ha^{-1}, respectively in cauliflower cv. RC Job-1.

Thakre *et al*. (2005) observed that increased level of sulphur significantly increased the yield of brinjal. The highest yield (150.61 q /ha) was recorded with the application of 40 kg S ha-1 in the form of gypsum.

Hamsaveni et al (2003) reported that application of S through gypsum (150 kg ha^{-1}) resulted in taller plants, early in days to 50 percent flowering, larger sized fruits and higher number of fruits per plant in tomato. The fruit yield (32.58 t ha^{-1}) was maximum with 150 kg ha^{-1} gypsum application.

Hamsaveni (2002) observed that in black clayey soil application of gypsum @ 150 kg ha-1 resulted in maximum plant height (14.3 cm), fruit size (17.70 cm), number of fruits per plant (44.97) and fruit yield of tomato (34.01 t/ha) compared to control.

Sureshbabu (2001) reported that soil application of gypsum (150 kg/ha) increased the plant height, number of fruit per plant (23.89), number of seeds per fruit (381.84), total fruit yield (31.48 t/ha) and seed yield (701.72 kg /ha) of brinjal compared to lower doses of gypsum and control.

Sundaravadivel *et al*. (1996) reported that significantly higher fruit yield (1492 kg/ha) of chilli when sulphur (one tonne of gypsum) was added through irrigation water compared to other treatments. Gangadhar (2000) reported that the application of nitrogen sulphur, zinc alone and in different combinations significantly increased the grain and straw yield. The maximum grain yield (2306 kg/ha) of coriander was recorded with the N80, $S_{1.2}$ $Zn_{2.5}$ levels.

2.3 Combined effect of Phosphorus and Sulphur

Kalpana *et al*. (2015) conducted a field experiment in calcareous clay loam soil to ascertain the quantity of P and S required to enhance the productivity of tomato, with five levels of P_2O_5 (312.5, 250, 187.5, 125 and 0 kg ha^{-1}) and four levels of S, applied at the rate of 2.5, 1.5, 0.5 and 0 per cent (w/w) equivalent to active $CaCO_3$ in soil. Increased rate of P and S application enhanced tomato growth recording highest with P312.5+ S2.5 which was on par with P250+S2.5. But, the highest fruit setting rate (69.37%) was obtained with P250+S2.5 resulting in higher number of fruits per cluster (4.94), fruits per plant (41.17), fruit weight (77.60 g), fruit diameter (5.17cm). All these yield parameters were manifested into marketable tomato fruit yield recording maximum of 42.30 t ha^{-1} with P250+S2.5. The study established that application of 250 kg ha^{-1} P +2.5% S found to be statistically optimum for tomato in terms of its yield (42.30 ton ha^{-1}).

Gopal *et al.* (2003) studied the effects of P (sodium dihydrogen orthophosphate) at deficient (0.01 mM), subnormal (0.33 mM) and normal (2.0 mM) levels, and S (sodium sulfate) at deficient (0.02 mM) and normal (2.0 mM) levels on the performance of tomato cv. Pusa Ruby were studied under greenhouse conditions. At 55 days after sowing, the colour of old leaves changed from green to bluish- green, and the diameter of the main stem and the number of leaves were reduced under P deficiency. Under S deficiency, intense chlorosis of young leaves and inhibition of plant growth were observed. P deficiency reduced biomass production, fruit yield, and contents of chlorophyll a and b, reducing sugar, nonreducing sugar, total sugar, starch, organic P, phospholipid, nucleic acid and phosphorylated protein; delayed fruit maturation; and increased peroxidase, ribonuclease and acid phosphatase activities in leaves. These effects were aggravated by S deficiency, suggesting the synergistic role of both nutrients.

Woods *et al.* (2000) concluded the effects of potassium and phosphorus fertilizers on the growth of tomatoes in moss peat over three years. Additions of sulphate of potash ranged from 0 to 200 g per bushel and super phosphate from 0 to 150 g in two factorial trials. Additional superphosphate or sulphate of potash reduced the fresh and dry weight of early plants in January in two years but not in February. Sulphate of potash or superphosphate had no effect on fresh weight, dry weight or flower number in autumn tomatoes. Sulphate of potash had no effect on flower number in any year, but additional phosphate increased flower number on the first truss in one year. Satisfactory early and autumn plants were obtained by adding 25 and 50 g sulphate of potash per bushel and 50 and 100 g superphosphate. The effects of fertilizer treatment on the nutrient content of plants and peat are given.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at theSher-e-Bangla Agricultural University farm, Dhaka, Bangladesh during the period from October 2017 to April 2018 to study the growth and yield of BARI tomato 11 in response to application of phosphorus and sulphur. The details of the materials and methods have been presented below:

3.1 Experimental location

The present piece of research work was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is90°33´ E longitude and 23°77´ N latitude with an elevation of 8.2 m from sea level. Location of the experimental site presented in Appendix I.

3.2 Soil

The soil of the experimental area belongs to the Modhupur Tract (UNDP, 1988) under AEZ No. 28 and was dark grey terrace soil. The selected plot was medium high land and the soil series was Tejgaon (FAO, 1988). The characteristics of the soil under the experimental plot were analyzed in the Soil Testing Laboratory, SRDI, Khamarbari, Dhaka. The details of morphological and chemical properties of initial soil of the experiment plot were presented in Appendix II.

3.3 Climate

The climate of experimental site was subtropical, characterized by three distinct seasons, the winter from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October (Edris et al., 1979). Details on the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e-Bangla Nagar, presented in Appendix III.

3.4 Test crop and its characteristics

Seeds of BARI tomato-11 was collected from Bangladesh Agricultural Research Institute (BARI), Joydevpur, Gazipur. After multilocation trials BARI released this variety for general cultivation with a popular name 'Jumka' in the year 1999. This variety is tolerant to bacterial wilt. Plants are tall and little bushy, fruits are small and single fruit weight is 8-10g. It is pulm shaped and borne in cluster. Fruits per cluster are 15-20 as like grape fruit. Average number fruits per plant are 180-200. Recommended yield per plant is 1kg. It's life time is 100-110 days and fruits are more sweet. Average per hectare yield is 35-40 ton in winter season. Storage capacity is 2 weeks in room temperature.

3.5 Experimental details

3.5.1 Treatments

The experiment comprised of two factors.

Factor A: Phosphorus (P) application - four levels

1. P_0 = 0 kg P ha^{-1} (Control)
2. P_1 = 20 kg P ha^{-1} (41.66 kg TSP ha^{-1})
3. P_2 = 30 kg P ha^{-1} (62.50 kg TSP ha^{-1})
4. P_3 = 40 kg P ha^{-1} (83.33 kg TSP ha^{-1})

Factor B: Sulphur (S) application - four levels

1. S_0 = 0 kg S ha^{-1} (Control)
2. S_1 = 10 kg S ha^{-1} (42.55 kg gypsum ha^{-1})
3. S_2 = 15 kg S ha^{-1} (63.82 kg gypsum ha^{-1})
4. S_3 = 20 kg S ha^{-1} (85.10 kg gypsum ha^{-1})

Treatment combinations – Sixteen (16) treatment combinations

P_0S_0, P_0S_1, P_0S_2, P_0S_3, P_1S_0, P_1S_1, P_1S_2, P_1S_3, P_2S_0, P_2S_1, P_2S_2, P_2S_3, P_3S_0, P_3S_1, P_3S_2 and P_3S_3.

3.5.2 Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The layout of the experiment was prepared for distributing the combination of doses of Phosphorus (P) and Sulphur (S). The 16 treatment combinations of the experiment were assigned at random into 48 plots. The size of each unit plot was 2.5 m × 0.7 m (= 1.75 m^2). The distance between blocks and plots were 0.5 m and 0.25 m respectively. The layout of the experiment field is presented in Appendix IV.

3.5.3 Variety used and seed collection

BARI tomato-11, a high yielding variety of tomato (*Solanum lycopersicum* L.) developed by Bangladesh Agricultural Research Institute (BARI), Gazipur was used as test crop. Seeds were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.6 Raising of seedlings

The land selected for nursery beds were well drained and were sandy loam type soil. The area was well prepared and converted into loose friable and dried mass to obtain fine tilth. All weeds and dead roots were removed and the soil was mixed with well rotten cowdung at the rate of 5 kg/bed. Seed bed size was 3m × 1m raised above the ground level maintaining a spacing of 50 cm between the beds. One seed bed was prepared for raising the seedlings. Ten (10) grams of seeds were sown in each seed bed on 30 October, 2017. After sowing, the seeds were covered with light soil. Complete germination of the seeds took place with 5 days after seed sowing. Necessary shading was made by bamboo mat (chatai) from scorching sunshine or rain. No chemical fertilizer was used in the seed bed.

3.7 Preparation of the main field

The plot selected for the experiment was opened in the last week of October, 2017 with a power tiller, and was exposed to the sun for a few days, after, which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubble were removed and finally obtained a desirable tilth of soil for transplanting. The land operation was completed on 5 November 2017. The individual plots were made by making ridges (20 cm high) around each plot to restrict lateral runoff of irrigation water.

3.8 Fertilizers and manure application

The N, P, K, and S nutrients were applied through urea, Triple super phosphate (TSP), Muriate of potash (MoP) and Gypsum, respectively. Phosphorus (P) and Sulphur (S) were applied as per treatment where rest of the nutrients was applied according to Krishi Projukti Hat Boi, 2016. Name and doses of nutrients were as follows:

Plant nutrients	Manure and fertilizer	Doses ha^{-1}
--	Cowdung	10 t
N	Urea	550 kg
P	TSP	As per treatment
K	MoP	250 kg
S	Gypsum	As per treatment

One third (1/3) of whole amount of Urea and full amount of TSP, MoP and Gypsum were applied at the time of final land preparation. The remaining Urea was top dressed in two equal installments- at 20 days after transplanting (DAT) and 50 DAT respectively.

3.9 Transplanting of seedlings

Healthy and uniform sized 35 days old seedlings were taken separately from the seed bed and were transplanted in the experimental field on 5 November, 2017 maintaining a spacing of 50 cm × 50 cm. The seed bed was watered before uprooting the seedlings so as to minimize the damage of the roots. This operation was carried out during late hours in the evening. The seedlings were watered after transplanting. Shading was provided by piece of banana leaf sheath for three days to protect the seedlings from the direct sun. A strip of the same crop was established around the experimental field as border crop to do gap filling and to check the border effect.

3.10 Intercultural Operation

After establishment of seedlings, various intercultural operations were accomplished for better growth and development of the tomato.

3.10.1 Gap filling and weeding

When the seedlings were established, the soil around the base of each seedling was pulverized. A few gaps filling were done by healthy plants from the border whenever it was required. Weeds of different types were controlled manually as and when necessary.

3.10.2 Irrigation

Irrigation was done at three times. The first irrigation was given in the field at 25 days after transplanting (DAT) through irrigation channel. The second irrigation was given at the stage of maximum vegetative growth stage (40 DAT). The final irrigation was given at the stage of fruit formation (60 DAT).

3.10.3 Plant protection

The crop was infested with cutworm, leaf hopper and others. The insects were controlled successfully by spraying Malathion 57 EC @ 2ml /L water. The insecticide was sprayed fortnightly from a week after transplanting to a week before first harvesting. During foggy weather precautionary measures against disease infestation specially late blight of tomato was taken by spraying Dithane M-45 fortnightly @ 2 g/L.

3.11 Harvesting

Fruits were harvested at 5 days intervals during maturity to ripening stage. The maturity of the crop was determined on the basis of red colouring of fruits. Harvesting was started from 15 January, 2018 and completed by 7 April, 2018.

3.12 Data Collection and Recording

Ten plants were selected randomly from each unit plot for recording data on crop parameters and the yield of grain and straw were taken plot wise. The following parameters were recorded during the study:

3.12.1 Growth parameters

1. Plant height (cm)
2. Branch length plant^{-1}
3. Number of branches plant^{-1}

3.12.2 Yield contributing parameters

1. Number of cluster plant^{-1}
2. Number of flowers cluster^{-1}
3. Number of fruits cluster^{-1}
4. Number of fruits plant^{-1}

3.12.3 Yield parameters

1. Number of fruits plot^{-1}
2. Fruit weight plot^{-1} (kg)
3. Fruit yield ha^{-1} (t)

3.12.4 Quality parameters

1. Nutrient content (N, P, K, and S) in shoot
2. Nutrient content (N, P, K, and S) in root

3.13 Procedure of recording data

3.13.1 Plant height (cm)

The height of plant was recorded in centimeter (cm) at the time of harvest. Data were recorded as the average of all plants (5 plants) of each plot. The height was measured from the ground level to the tip of the leaves.

3.13.2 Branch length plant^{-1}

Branch length was recorded in centimeter (cm) at the time of harvest. Data were recorded as the average of 5 plants in each plot. The branch length was measured from the base to the tip of the branch leaf.

3.13.3 Number of branches plant^{-1}

The total number of branches was counted from all plants (5 plants) of each plot. The average branches number was calculated which is termed as number of branches plant^{-1}.

3.13.4 Number of cluster plant^{-1}

The number of clusters was counted from all plants (5 plants) of each plot and the average number of clusters produced per plant was calculated.

3.13.5 Number of flowers cluster^{-1}

Total number of flowers and clusters was recorded from the five sample plants, and the average number of flowers cluster^{-1} was calculated by the following procedure

$$\text{Number of fruits cluster}^{-1} = \frac{\text{Total number of flowers from 5 plants}}{\text{Total number of clusters from 5 plants}}$$

3.13.6 Number of fruits cluster^{-1}

The number of fruits and clusters from first harvest to last harvest was recorded from the five plants, and the average number of fruits cluster^{-1} was recorded by the following calculation

$$\text{Number of fruits cluster}^{-1} = \frac{\text{Total number of fruits from 5 plants}}{\text{Total number of clusters from 5 plants}}$$

3.13.7 Number of fruits plant^{-1}

The total number of fruits was counted at first harvest to last harvest from all plants (5 plants) of each plot and then averaged to obtain number of fruits plant^{-1}.

3.13.8 Number of fruits plot^{-1}

Number of fruits was recorded at each harvest from all plants (5 plants) of each plot. Totaling of fruit was calculated till final harvest and expressed as number of fruits plot^{-1}.

3.13.9 Fruit weight plot^{-1} (kg)

A pan scale balance was used to take the weight of fruits per plot. It was measured by totaling of fruit yield from each unit plot during the period from first to final harvest and was recorded in kilogram.

3.13.10 Fruit yield ha^{-1} (t)

After collection of per plot yield, it was converted to ton per hectare by the following formula:

$$\text{Fruit yield per hectare (ton)} = \frac{\text{Fruit yield per plot (kg)} \times 10000 \text{ m}^2}{\text{Plot size (m}^2) \times 1\,000 \text{ kg}}$$

3.15.10 Chemical analysis

Chemical analysis was done in the laboratory following the procedure of nutrient content measurement regarding nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Nutrient content was measured in stem and fruit.

3.14 Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among the treatment by using the MSTAT-C computer package program. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatments means was estimated by the Least Significant Difference Test (LSD) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to investigate the growth and yield of BARI tomato 11 in response to application of phosphorus and sulphur. The analysis of variances for different characters has been presented in Appendices V to IX. Data on different parameters were analyzed statistically and the results have been presented through Figures and Tables. The results of the present study have been presented and discussed in this chapter under the following headings.

4.1 Growth parameters

4.1.1 Plant height

Effect of phosphorus

Plant height differed significantly due to the application of different levels of phosphorus (Fig. 1 and Appendix V). The tallest plant (110.40 cm) was produced by P_3 (40 kg P ha^{-1}) treatment, which was statistically identical with P_2 (30 kg P ha^{-1}). The shortest plant (103.30 cm) was produced by control treatment P_0 (0 kg P ha^{-1}). The plant height was increased possibly due to the readily available phosphorus, which might have encouraged more vegetative growth and development. Melton and Dufault (1991) reported that plant height was increased significantly as phosphorus level increased. Dhiman *et al*. (2018), Zhu and Ozores-Hampton (2017) and Rahaman *et al*. (2011) also found similar result on plant height.

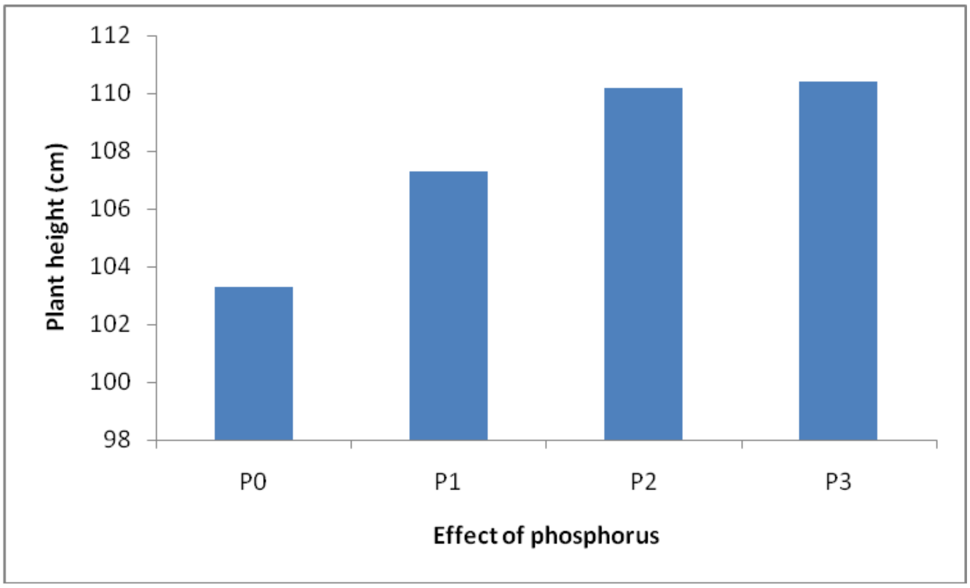

Fig. 1. Effect of phosphorus on plant height of BARI tomato 11

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

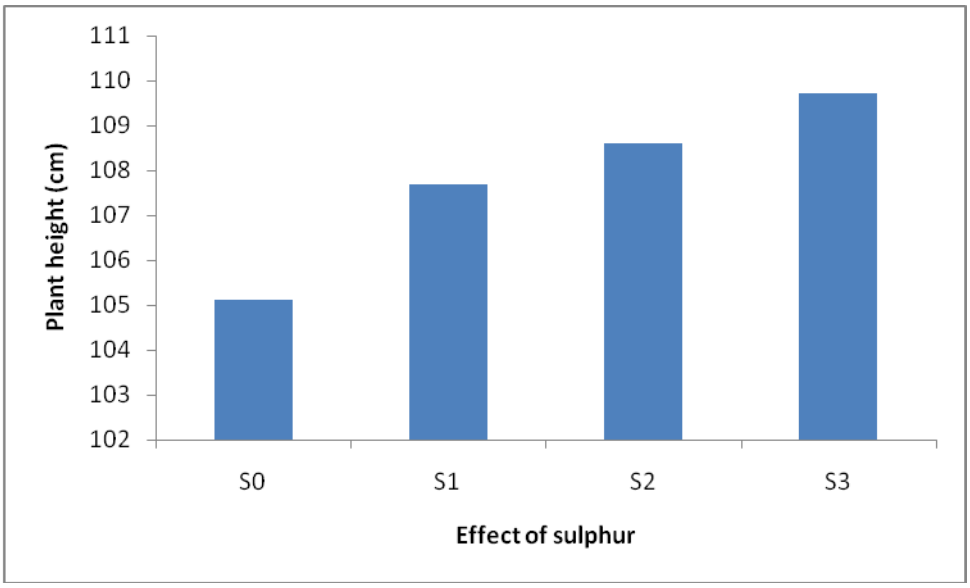

Fig. 2. Effect of sulphur on plant height of BARI tomato 11

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

Effect of sulphur

Different levels of sulphur application showed significant variations on the plant height of tomato (Fig. 2 and Appendix V). The longest plant (109.70 cm) was recorded from S_3 (20 kg S ha^{-1}) treatment which was statistically identical with S_1 (10 kg S ha^{-1}) and S_2 (15 kg S ha^{-1}). The shortest plant (105.10 cm) was obtained from control treatment S_0 (0 kg S ha^{-1}). Muthanna *et al.* (2017) and Saeed and Ahmad (2009) also found similar result which supported the present study.

Combined effect of phosphorus and sulphur

A significant variation was found due to combined effect of phosphorus and sulphur in terms of plant height (Table 1 and Appendix V). The longest plant (117.00 cm) was recorded from the combined effect of P_3S_3 which was significantly different from all other treatment combinations followed by P_2S_3. The shortest plant (97.99 cm) was found from the treatment combination of P_0S_0 which was also significantly different from all other treatment combinations followed by P_0S_1 and P_0S_2.

4.1.2 Branch length plant^{-1}

Effect of phosphorus

In case of branch length plant^{-1}, significant difference was observed due to the application of different levels of phosphorus (Fig. 3 and Appendix V). Results revealed that the maximum branch length plant^{-1} (27.17 cm) was recorded from the treatment P_3 (40 kg P ha^{-1}) which was significantly different from other P treatments followed by P_3 (40 kg P ha^{-1}). The treatment P_0 (0 kg P ha^{-1}) gave the minimum branch length plant^{-1} (24.47 cm) which was statistically identical with P_2 (30 kg P ha^{-1}). Similar result was also obtained by Kumar *et al.* (2013).

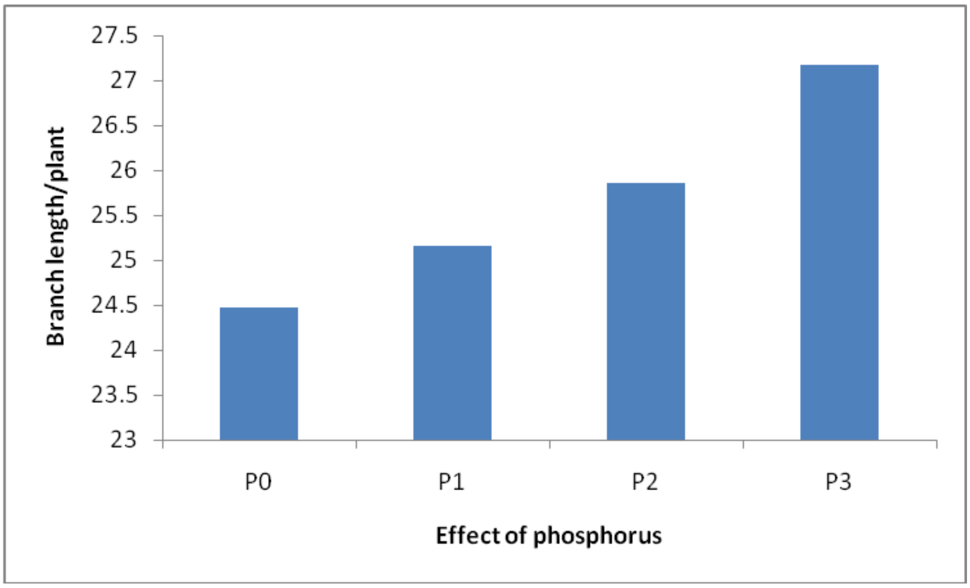

Fig. 3. Effect of phosphorus on branch length plant^{-1} of BARI tomato 11

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

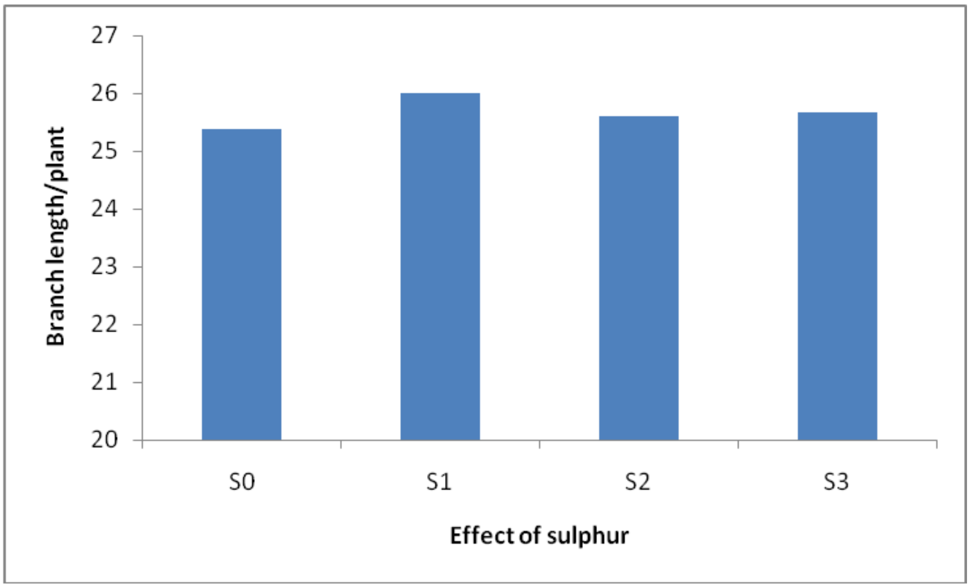

Fig. 4. Effect of sulphur on branch length plant^{-1} of BARI tomato 11

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

Effect of sulphur

There was no significant variations on branch length plant^{-1} due to different levels of sulphur application (Fig. 4 and Appendix V). But the maximum branch length plant^{-1} (25.67 cm) was recorded from S_3 (20 kg S ha^{-1}) and the minimum branch length plant^{-1} (25.37 cm) was obtained from S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Combined effect of phosphorus and sulphur showed a significant variation in terms of branch length plant^{-1} (Table 1 and Appendix V). Results exposed that the maximum branch length plant^{-1} (27.67 cm) was recorded from the combined effect of P_3S_3, which was statistically similar with the treatment combination of P_2S_2 and P_3S_1. The minimum branch length plant^{-1} (22.85 cm) was achieved from the treatment combination of P_0S_0 which was significantly different from all other treatment combinations followed by P_0S_1.

4.1.3 Number of branches plant^{-1}

Effect of phosphorus

Number of branch plant^{-1} showed significant variation due to the application of different levels of phosphorus (Fig. 5. and Appendix V). The maximum number of branch plant^{-1} (5.94) was recorded from P_2 (30 kg P ha^{-1}) followed by P_1 (20 kg P ha^{-1}) and P_3 (40 kg P ha^{-1}), while the control treatment P_0 (0 kg P ha^{-1}) gave the minimum number of branch plant^{-1} (5.17). These results indicate that phosphorus contribute to the growth parameters of tomato, which ensured the maximum number of branch than control. Kumar *et al.* (2013) and Rahaman *et al.* (2011) also found similar result which supported the present study.

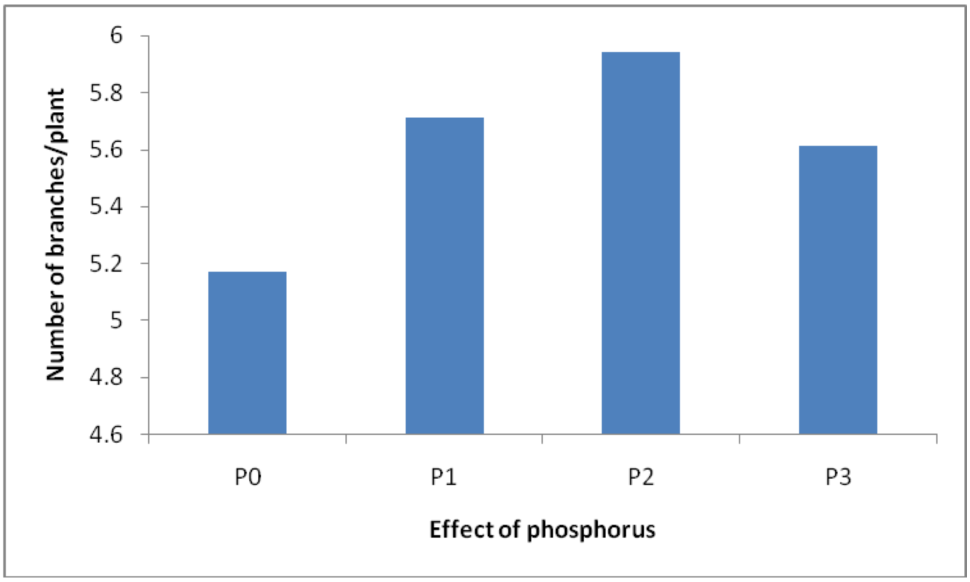

Fig. 5. Effect of phosphorus on number of branches plant^{-1} of BARI tomato 11

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

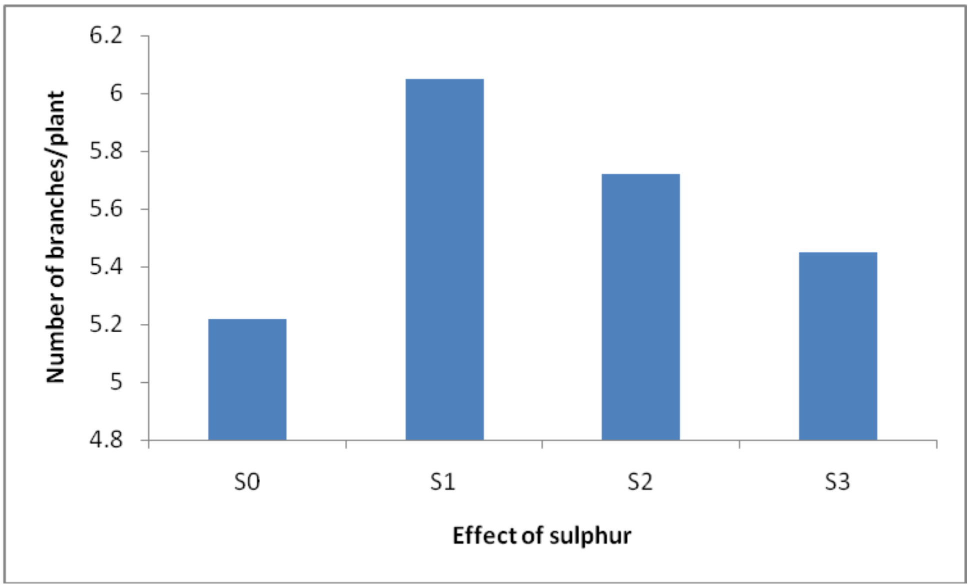

Fig. 6. Effect of sulphur on number of branches plant^{-1}of BARI tomato 11

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

Effect of sulphur

Application of different sulphur levels showed significant variation on number of branch plant^{-1} (Fig. 6. and Appendix V). Results revealed that the maximum number of branch plant^{-1} (6.05) was recorded from S_1 (10 kg S ha^{-1}) followed by S_2 (15 kg S ha^{-1}). The minimum number of branch plant^{-1} (5.22) was obtained from control treatment S_0 (0 kg S ha^{-1}). From the results it was found that S application @ 10 kg ha^{-1} was more effective than other S treatments under the trial. Similar result was also observed by Devi *et al*. (2012).

Combined effect of phosphorus and sulphur

A significant variation was found for the combined effect of phosphorus and sulphur in terms of number of branch plant^{-1} (Table 1 and Appendix V). The maximum number of branch plant^{-1} (6.64) was recorded from the combined effect of P_2S_1 that was statistically identical with P_1S_1. On the other hand P_0S_0 gave the minimum number of branch plant^{-1} (4.50) which was statistically identical with the treatment combination of P_0S_2 and P_1S_0.

Table 1. Combined effect of phosphorus and sulphur on growth parameters of BARI tomato 11

Treatment	Growth parameters at harvest		
	Plant height (cm)	Branch length plant^{-1}	Number of branches plant^{-1}
P_0S_0	97.99 h	22.85 h	4.50 h
P_0S_1	103.30 g	24.63 g	5.73 e
P_0S_2	103.50 g	24.82 fg	4.67 h
P_0S_3	108.40 de	25.59 d	5.77 de
P_1S_0	106.10 f	25.46 de	4.53 h
P_1S_1	109.50 d	25.49 de	6.63 a
P_1S_2	107.00 ef	24.49 g	5.97 cd
P_1S_3	111.50 c	25.18 def	5.72 e
P_2S_0	108.10 de	26.84 b	5.60 e
P_2S_1	106.00 f	25.00 efg	6.64 a
P_2S_2	105.70 f	27.29 ab	6.20 b
P_2S_3	113.20 b	26.90 b	5.30 f
P_3S_0	109.30 d	26.27 c	6.23 b
P_3S_1	108.10 de	27.28 ab	5.19 fg
P_3S_2	109.80 d	24.89 fg	6.03 bc
P_3S_3	117.00 a	27.67 a	5.00 g
$LSD_{0.05}$	1.605	0.4975	0.217
CV(%)	10.08	7.99	6.31

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

4.2 Yield contributing parameters

4.2.1 Number of flower clusters plant^{-1}

Effect of phosphorus

Variation among different doses of phosphorus on the number of flower clusters plant^{-1} showed significant variation (Table 2 and Appendix VI). The maximum number of flower clusters plant^{-1} (12.35) was noticed where plants were fertilized with P_2 (30 kg P ha^{-1}) which was statistically identical with P_3 (40 kg P ha^{-1}). The lowest number of flower clusters plant^{-1} (11.93) was noticed at P_0 (0 kg P ha^{-1}) (control) followed by P_1 (20 kg P ha^{-1}). Similar result was also observed by Rahaman *et al*. (2011).

Effect of sulphur

There were significant variations among the different doses of sulphur in respect of flower clusters $plant^{-1}$ (Table 2 and Appendix VI). The maximum number of flower clusters $plant^{-1}$ (12.75) was found at S_1 (10 kg S ha^{-1}) level which was statistically identical with S_2 (15 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}) doses where the minimum number of flower clusters $plant^{-1}$ (10.78) was found from the control treatment S_0 (0 kg S ha^{-1}). The results clearly showed that the number of flower clusters $plant^{-1}$ was gradually decreased with increasing levels of sulphur. The result obtained from the present was conformity with the findings of Saeed and Ahmad (2009).

Combined effect of phosphorus and sulphur

Combined effect of different doses of phosphorus and sulphur ron on the number of flower cluster $plant^{-1}$ was found to be statistically significant (Table 2 and Appendix VI). The number of flower clusters $plant^{-1}$ varied from 9.93 to 13.03. The maximum number of flower clusters $plant^{-1}$ (13.03) was recorded from the treatment combination of P_2S_1 which was statistically similar with the treatment combination of P_0S_2, P_0S_3, P_1S_3, P_2S_2 and P_3S_3. The minimum number of flower clusters $plant^{-1}$ (9.93) was counted from the treatment combination of P_0S_0 followed by P_1S_0 and P_2S_0.

4.2.2 Number of flowers $cluster^{-1}$

Effect of phosphorus

There was significant effect of different doses of phosphorus on the number of flowers $cluster^{-1}$ (Table 2 and Appendix VI). The maximum number of flowers $cluster^{-1}$ (27.49) was noticed where plants were fertilized with P_2 (30 kg P ha^{-1}) which was significantly different from other P treatments followed by P_1 (20 kg

P ha^{-1}) and P_3 (40 kg P ha^{-1}). The lowest number of flowers cluster^{-1} (24.08) was noticed at P_0 (0 kg P ha^{-1}) treatment. Dhiman *et al*. (2018), Rahaman *et al.* (2011) and Shukla *et al.* (2006) also found similar result with the present study.

Effect of sulphur

Effect of different doses of sulphur fertilizers on number of flowers cluster^{-1} was significant (Table 2 and Appendix VI). The maximum number of flowers cluster^{-1} (27.13) was found at S_1 (10 kg S ha^{-1}) level which was significantly different from other S levels followed by S_2 (15 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}) where the minimum number of flowers cluster^{-1} (23.87) was found from the control treatment S_0 (0 kg S ha^{-1}). The results clearly showed that number of flowers cluster^{-1} was gradually decreased with increasing levels of sulphur. Saeed and Ahmad (2009) also found similar result with the present study.

Combined effect of phosphorus and sulphur

Effect of different doses of phosphorus and sulphur nutrients on the number of flowers cluster^{-1} was significantly influenced (Table 2 and Appendix VI). The maximum number of flowers cluster^{-1} (30.07) was recorded from the treatment combination of P_2S_1 which was significantly different from other treatment combinations followed by P_1S_2. The minimum number of flowers cluster^{-1} (23.21) was counted from the treatment combination of P_0S_0 which was statistically similar with the treatment combination of P_1S_0.

4.2.3 Number of fruits cluster^{-1}

Effect of phosphorus

Variation among different doses of phosphorus on the number of fruits cluster^{-1} showed significant variation (Table 2 and Appendix VI). The maximum number of fruits cluster^{-1} (20.69) was noticed from the treatment P_2 (30 kg P ha^{-1}) which was significantly different from other P treatments. The lowest number of fruits cluster^{-1} (17.78) was found from control treatment P_0 (0 kg P ha^{-1}). Dhiman *et al*. (2018), Rahaman *et al*. (2011) and Shukla *et al.* (2006) also found similar result on number of fruits cluster^{-1}.

Effect of sulphur

There were significant variations among the different doses of sulphur in respect of number of fruits cluster^{-1} (Table 2 and Appendix VI). The maximum number of fruits cluster^{-1} (20.23) was found at S_1 (10 kg S ha^{-1}) level which was statistically similar with S_2 (15 kg S ha^{-1}) whereas the minimum number of fruits cluster^{-1} (19.83) was found from the control treatment S_0 (0 kg S ha^{-1}). The results clearly showed that the number of fruits cluster^{-1} was gradually decreased with increasing levels of sulphur. Similar result was also found by Saeed and Ahmad (2009).

Combined effect of phosphorus and sulphur

Combined effect of different doses of phosphorus and sulphur ron on the number of fruits cluster^{-1} was found to be statistically significant (Table 2 and Appendix VI). The maximum number of fruits cluster^{-1} (22.10) was recorded from the treatment combination of P_2S_1 which was statistically similar with the treatment combination of P_2S_2. The minimum number of fruits cluster^{-1} (17.13) was counted from the treatment combination of P_0S_0 which was statistically similar with the treatment combination of P_1S_0 and P_2S_0.

4.2.4 Number of fruits plant^{-1}

Effect of phosphorus

There was significant effect of different doses of phosphorus on the number of fruits plant^{-1} (Table 2 and Appendix VI). The maximum number of fruits plant^{-1} (255.70) was noticed where plants were fertilized with P_2 (30 kg P ha^{-1}) which was significantly different from other P treatments followed by P_3 (40 kg P ha^{-1}). The lowest number of fruits plant^{-1} (209.10) was obtained from P_0 (0 kg P ha^{-1}) treatment. The results indicated that the number of fruits plant^{-1} was increased with increasing of P levels to a certain levels and then decreased with increasing levels of phosphorus. The result on number of fruits plant^{-1} under the present study was similar with the findings of Dhiman *et al*. (2018) and Rahaman *et al*. (2011).

Effect of sulphur

Effect of different doses of sulphur fertilizers on number of fruits plant^{-1} was significant (Table 2 and Appendix VI). The maximum number of fruits plant^{-1} (253.40) was found at S_1 (10 kg S ha^{-1}) level which was statistically identical with S_2 (15 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}) where the minimum number of fruits plant^{-1} (187.70) was found from the control treatment S_0 (0 kg S ha^{-1}). Saeed and Ahmad (2009) also found similar result which supported the present study.

Combined effect of phosphorus and sulphur

Effect of different doses of phosphorus and sulphur nutrients on the number of fruits plant^{-1} was significantly influenced (Table 2 and Appendix VI). The maximum number of fruits plant^{-1} (284.10) was recorded from the treatment combination of P_2S_1 which was significantly different from other treatment combinations followed by P_2S_2. The minimum number of fruits plant^{-1} (169.00) was counted from the treatment combination of P_0S_0 which was also significantly different from other treatment combination followed by P_1S_0 and P_2S_0.

Table 2. Effect of phosphorus and sulphur and also their combination on yield contributing parameters of BARI tomato 11

Treatment	Yield contributing parameters			
	Number of flower cluster plant^{-1}	Number of flowers cluster^{-1}	Number of fruits cluster^{-1}	Number of fruits plant^{-1}
Effect of phosphorus				
P_0	11.93 c	24.08 c	17.78 c	209.10 d
P_1	12.09 b	26.01 b	19.31 b	233.90 c
P_2	12.35 a	27.49 a	20.69 a	255.70 a
P_3	12.31 a	26.20 b	19.82 b	246.30 b
$LSD_{0.05}$	0.1087	0.2676	0.5673	2.796
CV(%)	11.93	6.10	7.75	9.76
Effect of sulphur				
S_0	10.78 b	23.87 c	17.47 c	187.70 b
S_1	12.75 a	27.13 a	20.23 a	253.40 a
S_2	12.71 a	26.57 b	20.07 ab	251.00 a
S_3	12.43 a	26.22 b	19.83 b	252.70 a
$LSD_{0.05}$	0.8812	0.4276	0.3041	3.463
CV(%)	11.93	6.10	7.75	9.76
Combined effect of phosphorus and sulphur				
P_0S_0	9.93 h	23.21 g	17.13 i	169.00 k
P_0S_1	11.90 e	24.10 f	17.83 gh	206.80 i
P_0S_2	12.85 ab	24.48 f	17.91 gh	226.50 h
P_0S_3	12.86 ab	24.53 f	18.25 g	233.90 g
P_1S_0	11.00 g	23.87 fg	17.40 hi	188.20 j
P_1S_1	12.42 cd	27.13 cd	20.13 e	249.90 f
P_1S_2	12.23 d	26.93 cd	20.25 e	249.30 f
P_1S_3	12.69 abc	26.10 e	19.47 f	248.20 f
P_2S_0	10.81 g	24.13 f	17.58 hi	190.00 j
P_2S_1	13.03 a	30.07 a	22.10 a	284.10 a
P_2S_2	12.91 ab	28.07 b	21.70 ab	278.10 b
P_2S_3	12.67 bc	27.70 bc	21.37 bc	270.60 c
P_3S_0	11.38 f	24.27 f	17.77 gh	203.80 i
P_3S_1	12.58 bc	27.20 cd	20.87 cd	263.20 d
P_3S_2	12.67 bc	26.78 de	20.42 de	259.90 de
P_3S_3	12.76 abc	26.55 de	20.23 e	258.20 e
$LSD_{0.05}$	0.3029	0.7513	0.5605	4.489
CV(%)	11.93	6.10	7.75	9.76

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

4.3 Yield parameters

4.3.1 Number of fruits plot^{-1}

Effect of phosphorus

Number of fruits plot^{-1} showed significant variation due to the application of different levels of phosphorus (Table 1 and Appendix V). The maximum number of fruits plot^{-1} (1023.00) was recorded from P_2 (30 kg P ha^{-1}) which was significantly different from other treatments followed by P_3 (40 kg P ha^{-1}), while the control treatment P_0 (0 kg P ha^{-1}) gave the minimum number of fruits plot^{-1} (836.30). From the results it was found that P application @30 kg ha^{-1} was more effective than other P doses under the present study. Dhiman *et al*. (2018) also found similar result which supported the present study.

Effect of sulphur

Application of different sulphur levels showed significant variation on number of fruits plot^{-1} (Table 1 and Appendix V). Results revealed that the maximum number of fruits plot^{-1} (1014.00) was recorded from S_1 (10 kg S ha^{-1}) which was statistically identical with S_2 (15 kg S ha^{-1}). The minimum number of fruits plot^{-1} (750.90) was obtained from control treatment S_0 (0 kg S ha^{-1}). From the results it was found that S application @ 10 kg ha^{-1} was more effective than other S treatments under the trial.

Combined effect of phosphorus and sulphur

A significant variation was found for the combined effect of phosphorus and sulphur in terms of number of fruits plot^{-1} (Table 1 and Appendix V). The maximum number of fruits plot^{-1} (1136.00) was recorded from the combined effect of P_2S_1 which was significantly different from other treatment combinations followed by P_2S_2. On the other hand P_0S_0 gave the minimum number of fruits plot^{-1} (676.00) which was also significantly different from other treatment combinations followed by P_1S_0 and P_2S_0.

4.3.2 Fruit weight plot^{-1}

Effect of phosphorus

Variation among different doses of phosphorus on the fruit weight plot^{-1} showed significant variation (Table 2 and Appendix VI). The maximum fruit weight plot^{-1} (7.03 kg) was noticed where plants were fertilized with P_2 (30 kg P ha^{-1}) which was significantly different from other treatments followed by P_3 (40 kg P ha^{-1}). The lowest fruit weight plot^{-1} (5.70 kg) was observed from the treatment P_0 (0 kg P ha^{-1}) (control) followed by P_1 (20 kg P ha^{-1}). Similar result was also observed by Dhiman *et al*. (2018).

Effect of sulphur

There were significant variations among the different doses of sulphur in respect of fruit weight plot^{-1} (Table 2 and Appendix VI). The maximum fruit weight plot^{-1} (6.87 kg) was found at S_1 (10 kg S ha^{-1}) level which was statistically identical with S_2 (15 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}) doses where the minimum fruit weight plot^{-1} (5.28 kg) was found from the control treatment S_0 (0 kg S ha^{-1}). The results clearly showed that the fruit weight plot^{-1} was gradually decreased with increasing levels of sulphur.

Combined effect of phosphorus and sulphur

Combined effect of different doses of phosphorus and sulphur on the fruit weight plot^{-1} was found to be statistically significant (Table 2 and Appendix VI). The fruit weight plot^{-1} varied from 4.47 to 7.63. The maximum fruit weight plot^{-1} (7.63 kg) was recorded from the treatment combination of P_2S_1 which was statistically similar with the treatment combination of P_2S_2. The minimum fruit weight plot^{-1} (4.47 kg) was counted from the treatment combination of P_0S_0 followed by P_1S_0.

4.3.3 Fruit yield ha^{-1}

Effect of phosphorus

There was significant effect of different doses of phosphorus on the fruit yield ha^{-1} (Table 2 and Appendix VI). The highest fruit yield ha^{-1} (40.15 t) was noticed where plants were fertilized with P_2 (30 kg P ha^{-1}) which was significantly different from other P treatments followed by P_3 (40 kg P ha^{-1}). Control treatment P_0 (0 kg P ha^{-1}) gave the lowest fruit yield ha^{-1} (32.58 t). Dhiman *et al*. (2018), Zhu and Ozores-Hampton (2017) and Rahaman *et al*. (2011) also found similar result which supported the present study.

Effect of sulphur

Effect of different doses of sulphur fertilizers on fruit yield ha^{-1} was significant (Table 2 and Appendix VI). The highest fruit yield ha^{-1} (39.23 t) was found at S_1 (10 kg S ha^{-1}) level which was significantly different from other S levels followed by S_2 (15 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}) where the lowest fruit yield ha^{-1} (30.17 t) was found from the control treatment S_0 (0 kg S ha^{-1}). The results clearly showed that fruit yield ha^{-1} was gradually decreased with increasing levels of sulphur.

Zelená *et al*. (2009), Saeed and Ahmad (2009) and Santos *et al*. (2007)

Combined effect of phosphorus and sulphur

Effect of different doses of phosphorus and sulphur nutrients on the fruit yield ha^{-1} was significantly influenced (Table 2 and Appendix VI). The highest fruit yield ha^{-1} (43.59 t) was recorded from the treatment combination of P_2S_1 which was statistically similar with the treatment combination of P_2S_2, P_2S_3 and P_3S_1. The lowest fruit yield ha^{-1} (25.51 t) was counted from the treatment combination of P_0S_0 which was significantly different from other treatment combinations followed by P_1S_0. Kalpana *et al.* (2015) also found similar result which supported the present study.

Table 3. Effect of phosphorus and sulphur and also their combination on yield parameters of BARI tomato 11

Treatment	Yield parameters

	Number of fruits plot^{-1}	Fruit weight plot^{-1} (kg)	Fruit yield ha^{-1} (t)
Effect of phosphorus			
P_0	836.30 d	5.704 d	32.58 d
P_1	935.50 c	6.070 c	34.69 c
P_2	1023.00 a	7.027 a	40.15 a
P_3	985.00 b	6.762 b	38.64 b
$LSD_{0.05}$	3.533	0.2283	0.5247
CV(%)	12.66	8.64	9.63
Effect of sulphur			
S_0	750.90 c	5.281 b	30.17 d
S_1	1014.00 a	6.865 a	39.23 a
S_2	1011.00 a	6.765 a	38.66 b
S_3	1004.00 b	6.652 a	38.01 c
$LSD_{0.05}$	3.725	0.2283	0.3691
CV(%)	12.66	8.64	9.63
Combined effect of phosphorus and sulphur			
P_0S_0	676.00 *l*	4.468 k	25.51 i
P_0S_1	827.30 i	5.980 gh	34.15 efg
P_0S_2	906.00 h	6.163 fg	35.21 ef
P_0S_3	935.70 g	6.207 f	35.47 de
P_1S_0	752.70 k	5.217 j	29.80 h
P_1S_1	999.70 f	6.577 e	37.60 cd
P_1S_2	997.00 f	6.273 f	35.86 de
P_1S_3	992.70 f	6.213 f	35.52 e
P_2S_0	760.00 k	5.633 i	32.18 g
P_2S_1	1136.00 a	7.627 a	43.59 a
P_2S_2	1112.00 b	7.467 ab	42.67 ab
P_2S_3	1082.00 c	7.380 b	42.17 ab
P_3S_0	815.00 j	5.807 hi	33.19 fg
P_3S_1	1053.00 d	7.277 bc	41.59 ab
P_3S_2	1040.00 e	7.157 c	40.91 b
P_3S_3	1033.00 e	6.807 d	38.89 c
$LSD_{0.05}$	9.859	0.2042	1.970
CV(%)	12.66	8.64	9.63

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

4.4 Quality parameters

4.4.1 Nutrient concentration in plant shoots

4.4.1.1 Nitrogen (N) concentration in plant shoots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a statistically significant variation in the nitrogen (N) concentration in plant shoot of tomato (Table 4 and Appendix VIII). The total N concentration in plant shoot varied from 1.50% to 2.54%. Among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest N concentration (2.54%) in shoot. The lowest value of N concentration was 1.50% under control treatment P_0 (0 kg P ha^{-1}).

Effect of sulphur

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the nitrogen (N) concentration in plant shoot of tomato (Table 4 and Appendix VIII). The total N content of the post harvest plant shoot varied from 1.68% to 2.46%. The highest total N content (1.68%) was observed in S_3 (20 kg S ha^{-1}) treatment. The lowest value of N concentration in plant shoot (2.46%) was observed under control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Significant effect of combined application of different doses of phosphorus and sulphur fertilizer on the nitrogen (N) concentration was observed in post harvest plant shoot of tomato (Table 4 and Appendix VIII). The highest concentration of N in plant shoot of tomato (2.72%) was recorded in the treatment combination of P_3S_3 which was statistically identical with P_3S_2 and statistically similar with the treatment combination of P_2S_2 and P_2S_3. On the other hand, the lowest N concentration (1.12%) in plant shoot was found in P_0S_0 followed by P_0S_1.

4.4.1.2 Phosphorus (P) concentration in plant shoots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a statistically significant variation in the phosphorus (P) concentration in plant shoot of tomato (Table 4 and Appendix VIII). The total P concentration in plant shoot varied from 0.275 ppm to 0.825 ppm. Among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest P concentration (0.825 ppm) in shoot which was statistically identical with P_2 (30 kg P ha^{-1}). The lowest value of P concentration was 0.275 ppm under control treatment P_0 (0 kg P ha^{-1}).

Effect of sulphur

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the phosphorus (P) concentration in plant shoot of tomato (Table 4 and Appendix VIII). The total P content of the post harvest plant shoot varied from 0.523 ppm to 0.62 ppm. The highest total P content (0.620 ppm) was observed in S_3 (20 kg S ha^{-1}) treatment which was significantly different from other treatments. The lowest value of P concentration in plant shoot (0.523 ppm) was observed under control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Significant effect of combined application of different doses of phosphorus and sulphur fertilizer on the phosphorus (P) concentration was observed in post harvest plant shoot of tomato (Table 4 and Appendix VIII). The highest concentration of P in plant shoot of tomato (0.88 ppm) was recorded in the treatment combination of P_3S_3 which was statistically similar with P_3S_2. The lowest P concentration (0.220 ppm) in plant shoot was found in P_0S_0 which was statistically identical with P_0S_2 and closely followed by P_0S_1.

4.4.1.3 Potassium (K) concentration in plant shoots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a statistically non-significant variation in the potassium (K) concentration in plant shoot of tomato (Table 4 and Appendix VIII). But among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest K concentration (0.030 ppm) and control treatment P_0 (0 kg P ha^{-1}) gave the lowest K concentration (0.017 ppm).

Effect of sulphur

The effect of different doses of sulphur fertilizer showed non-significant variation on potassium (K) concentration in plant shoot of tomato (Table 4 and Appendix VIII). But the highest total K content (0.032 ppm) was observed in S_3 (20 kg S ha^{-1}) treatment and the lowest K concentration in plant shoot (0.011 ppm) was observed from control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Non-significant effect of combined application of different doses of phosphorus and sulphur fertilizer on the potassium (K) concentration was observed in post harvest plant shoot of tomato (Table 4 and Appendix VIII). But the highest concentration of K in plant shoot of tomato (0.042 ppm) was recorded in the treatment combination of P_3S_2 and the lowest K concentration (0.009 ppm) in plant shoot was found in P_0S_0.

4.4.1.4 Sulphur (S) concentration in plant shoots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a significant influence on sulphur (S) concentration in plant shoot of tomato (Table 4 and Appendix VIII). The total S concentration in plant shoot varied from 0.965 ppm to 1.06 ppm. Among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest S concentration (1.06 ppm) in shoot followed by P_2 (30 kg P ha^{-1}). The lowest S concentration (0.965 ppm) was found under control treatment P_0 (0 kg P ha^{-1}) which was statistically identical with P_1 (20 kg P ha^{-1}) treatment.

Effect of sulphur

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the sulphur (S) concentration in plant shoot of tomato (Table 4 and Appendix VIII). The total S content of the post harvest plant shoot varied from 0.50 ppm to 1.325 ppm. The highest total S content (1.325 ppm) was observed in S_3 (20 kg S ha^{-1}) treatment which was significantly different from others. The lowest S concentration in plant shoot (0.50 ppm) was observed in control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Combined application of different doses of phosphorus and sulphur fertilizer showed significant effect of on sulphur (S) concentration in post harvest plant shoot of tomato (Table 4 and Appendix VIII). The highest concentration of S in plant shoot (1.38 ppm) was recorded in the treatment combination of P_0S_3 which was statistically identical with P_3S_3 and statistically similar with the treatment combination of P_2S_3. On the other hand, the lowest S concentration (0.44 ppm) in plant shoot was found in P_0S_0 which was statistically similar with P_1S_0 and P_2S_0.

Table 4. Effect of phosphorus and sulphur and also their combination on nutrient concentration in shoot of BARI tomato 11

Treatment	Nutrient concentration in shoot			
	N (%)	P (ppm)	K (ppm)	S (ppm)
Effect of phosphorus				
P_0	1.50 d	0.275 c	0.017	0.965 c
P_1	2.09 c	0.468 b	0.022	0.948 c
P_2	2.40 b	0.723 a	0.026	1.005 b
P_3	2.54 a	0.825 a	0.030	1.060 a
$LSD_{0.05}$	0.087	0.106	0.026 ^{NS}	0.037
CV(%)	3.33	2.12	1.15	1.71
Effect of sulphur				
S_0	1.68 d	0.523 c	0.011	0.500 d
S_1	2.09 c	0.568 b	0.021	0.985 c
S_2	2.29 b	0.570 b	0.029	1.168 b
S_3	2.46 a	0.620 a	0.032	1.325 a
$LSD_{0.05}$	0.089	0.037	0.026 ^{NS}	0.046
CV(%)	3.33	2.12	1.15	1.71
Combined effect of phosphorus and sulphur				
P_0S_0	1.12 i	0.220 h	0.009	0.440 h
P_0S_1	1.28 h	0.280 gh	0.015	0.920 f
P_0S_2	1.63 g	0.240 h	0.016	1.120 de
P_0S_3	1.98 e	0.320 g	0.026	1.380 a
P_1S_0	1.55 g	0.420 f	0.010	0.520 gh
P_1S_1	2.11 de	0.450 ef	0.018	0.880 f
P_1S_2	2.20 d	0.480 ef	0.025	1.150 cd
P_1S_3	2.48 c	0.520 e	0.033	1.240 bc
P_2S_0	1.84 f	0.670 d	0.012	0.480 gh
P_2S_1	2.45 c	0.740 cd	0.024	1.040 e
P_2S_2	2.66 ab	0.720 cd	0.035	1.180 cd
P_2S_3	2.65 ab	0.760 bc	0.032	1.320 ab
P_3S_0	2.22 d	0.780 bc	0.011	0.560 g
P_3S_1	2.52 bc	0.800 bc	0.028	1.100 de
P_3S_2	2.68 a	0.840 ab	0.042	1.220 c
P_3S_3	2.72 a	0.880 a	0.038	1.360 a
$LSD_{0.05}$	0.139	0.0746	0.053 ^{NS}	0.091
CV(%)	3.33	2.12	1.15	1.71

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

4.4.2 Nutrient concentration in plant roots

4.4.2.1 Nitrogen (N) concentration in plant roots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a statistically significant variation in the nitrogen (N) concentration in plant root of tomato (Table 5 and Appendix IX). The total N concentration in plant root varied from 2.37% to 1.41%. Among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest N concentration (2.37%) in root followed by P_1 (20 kg P ha^{-1}). The lowest value of N concentration was 1.41% under control treatment P_0 (0 kg P ha^{-1}) followed by P_2 (30 kg P ha^{-1}).

Effect of sulphur

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the nitrogen (N) concentration in plant root of tomato (Table 5 and Appendix IX). The total N content of the post harvest plant root varied from 1.53% to 2.24%. The highest total N content (1.53%) was observed in S_3 (20 kg S ha^{-1}) treatment followed by S_2 (15 kg S ha^{-1}). The lowest value of N concentration in plant root (2.24%) was observed under control treatment S_0 (0 kg S ha^{-1}) followed by S_1 (10 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Significant effect of combined application of different doses of phosphorus and sulphur fertilizer on the nitrogen (N) concentration was observed in post harvest plant root of tomato (Table 5 and Appendix IX). The highest concentration of N in plant root of tomato (2.58%) was recorded in the treatment combination of P_3S_3 which was statistically similar with P_3S_2 and statistically similar with the treatment combination of P_2S_2 and P_2S_3. On the other hand, the lowest N concentration (1.02%) in plant root was found in P_0S_0 which was statistically identical with P_0S_1.

4.4.2.2 Phosphorus (P) concentration in plant roots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a statistically significant variation in the phosphorus (P) concentration in plant root of tomato (Table 5 and Appendix IX). The total P concentration in plant root varied from 0.32 ppm to 0.905 ppm. Among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest P concentration (0.905 ppm) in root which was statistically identical with P_2 (30 kg P ha^{-1}). The lowest value of P concentration was 0.32 ppm under control treatment P_0 (0 kg P ha^{-1}) followed by P_2 (30 kg P ha^{-1}).

Effect of sulphur

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the phosphorus (P) concentration in plant root of tomato (Table 5 and Appendix IX). The total P content of the post harvest plant root varied from 0.595 ppm to 0.698 ppm. The highest total P content (0.698 ppm) was observed in S_3 (20 kg S ha^{-1}) treatment which was significantly different from other treatments. The lowest P concentration in plant root (0.595 ppm) was observed under control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Significant effect of combined application of different doses of phosphorus and sulphur fertilizer on the phosphorus (P) concentration was observed in post harvest plant root of tomato (Table 5 and Appendix IX). The highest concentration of P in plant root of tomato (0.95 ppm) was recorded in the treatment combination of P_3S_3 which was statistically similar with P_3S_2 and P_3S_1. The lowest P concentration (0.25 ppm) in plant root was found in P_0S_0 which was statistically similar with P_0S_1.

4.4.2.3 Potassium (K) concentration in plant roots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a statistically non-significant variation in the potassium (K) concentration in plant root of tomato (Table 5 and Appendix IX). But among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest K concentration (0.034 ppm) and control treatment P_0 (0 kg P ha^{-1}) gave the lowest K concentration (0.019 ppm).

Effect of sulphur

The effect of different doses of sulphur fertilizer showed non-significant variation on potassium (K) concentration in plant root of tomato (Table 5 and Appendix IX). But the highest total K content (0.036 ppm) was observed in S_3 (20 kg S ha^{-1}) treatment and the lowest K concentration in plant root (0.015 ppm) was observed from control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Non-significant effect of combined application of different doses of phosphorus and sulphur fertilizer on the potassium (K) concentration was observed in post harvest plant root of tomato (Table 5 and Appendix IX). But the highest concentration of K in plant root of tomato (0.045 ppm) was recorded in the treatment combination of P_3S_2 and the lowest K concentration (0.013 ppm) in plant root was found in P_0S_0.

4.4.2.4 Sulphur (S) concentration in plant roots

Effect of phosphorus

The effect of different doses of phosphorus fertilizer showed a significant influence on sulphur (S) concentration in plant root of tomato (Table 5 and

Appendix IX). The total S concentration in plant root varied from 1.04 ppm to 1.145 ppm. Among the different doses of phosphorus fertilizer, P_3 (40 kg P ha^{-1}) treatment showed the highest S concentration (11.145 ppm) in root which was statistically identical with P_2 (30 kg P ha^{-1}). The lowest S concentration (1.04 ppm) was found under control treatment P_0 (0 kg P ha^{-1}) which was statistically identical with P_1 (20 kg P ha^{-1}) treatment.

Effect of sulphur

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the sulphur (S) concentration in plant root of tomato (Table 5 and Appendix IX). The total S content of the post harvest plant root varied from 0.57 ppm to 1.41 ppm. The highest total S content (1.41 ppm) was observed in S_3 (20 kg S ha^{-1}) treatment which was significantly different from others. The lowest S concentration in plant root (0.57 ppm) was observed in control treatment S_0 (0 kg S ha^{-1}).

Combined effect of phosphorus and sulphur

Combined application of different doses of phosphorus and sulphur fertilizer showed significant effect of on sulphur (S) concentration in post harvest plant root of tomato (Table 5 and Appendix IX). The highest concentration of S in plant root (1.45 ppm) was recorded in the treatment combination of P_3S_3 which was statistically similar with the treatment combination of P_0S_3, P_1S_3 and P_2S_3. On the other hand, the lowest S concentration (0.48 ppm) in plant root was found in P_0S_0 which was statistically similar with the treatment combination of P_1S_0.

Table 5. Effect of phosphorus and sulphur and also their combination on nutrient concentration in root of BARI tomato 11

Treatment	Nutrient concentration in root			
	N (%)	P (ppm)	K (ppm)	S (ppm)
Effect of phosphorus				
P_0	1.41 d	0.320 c	0.019	1.040 b
P_1	1.80 c	0.543 b	0.025	1.043 b
P_2	2.12 b	0.802 a	0.029	1.117 a
P_3	2.37 a	0.905 a	0.034	1.145 a
$LSD_{0.05}$	0.099	0.109	0.026 ^{NS}	0.04567
CV(%)	1.25	3.05	2.71	1.92
Effect of sulphur				
S_0	1.53 d	0.595 c	0.015	0.570 d
S_1	1.83 c	0.627 b	0.024	1.087 c
S_2	2.09 b	0.650 b	0.032	1.275 b
S_3	2.24 a	0.698 a	0.036	1.413 a
$LSD_{0.05}$	0.091	0.026	0.027 ^{NS}	0.069
CV(%)	1.25	3.05	2.71	1.92
Combined effect of phosphorus and sulphur				
P_0S_0	1.02 i	0.250 h	0.013	0.480 i
P_0S_1	1.14 i	0.280 gh	0.015	1.060 fg
P_0S_2	1.58 g	0.330 g	0.015	1.220 de
P_0S_3	1.88 e	0.420 f	0.028	1.400 abc
P_1S_0	1.33 h	0.500 e	0.015	0.580 hi
P_1S_1	1.77 ef	0.500 e	0.022	0.960 g
P_1S_2	1.92 e	0.550 de	0.028	1.250 de
P_1S_3	2.18 cd	0.620 d	0.036	1.380 abc
P_2S_0	1.63 fg	0.780 c	0.016	0.600 h
P_2S_1	2.14 d	0.807 c	0.026	1.150 ef
P_2S_2	2.36 bc	0.820 c	0.039	1.300 cd
P_2S_3	2.33 bc	0.800 c	0.034	1.420 ab
P_3S_0	2.12 d	0.850 bc	0.016	0.620 h
P_3S_1	2.28 cd	0.920 ab	0.032	1.180 e
P_3S_2	2.49 ab	0.900 ab	0.045	1.330 bcd
P_3S_3	2.58 a	0.950 a	0.044	1.450 a
$LSD_{0.05}$	0.175	0.0746	0.053 ^{NS}	0.106
CV(%)	1.25	3.05	2.71	1.92

P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 30 kg P ha^{-1}), P_3 = 40 kg P ha^{-1}

S_0 = 0 kg S ha^{-1}, S_1 = 10 kg S ha^{-1}, S_2 = 15 kg S ha^{-1}, S_3 = 20 kg S ha^{-1}

CHAPTER V

SUMMARY AND CONCLUSION

The present experiment was conducted at the Research Field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207 during the period from October 2017 to April 2018 to study the growth and yield of BARI tomato 11 in response to application of phosphorus and sulphur. The tomato variety cv. BARI tomato 11 was used as planting materials for the present study which was collected from BRRI, Joydebpur, Gazipur. The two factors experiment consists with four levels of phosphorus (P) *viz.* P_0 :0 kg P ha^{-1} (control), P_1 :20 kg P ha^{-1}, P_2 :30 kg P ha^{-1} and P_3 :40 kg P ha^{-1} and four levels of sulphur *viz.*S_0 :0 kg S ha^{-1} (control), S_1 :10 kg S ha^{-1}, S_2 :15 kg S ha^{-1} and S_3 :20 kg S ha^{-1}. The experiment was laid out in Randomized Completele Block Design (RCBD) with three replications and analysis was done by the MSTAT-C package program whereas means were adjudged by DMRT at 5% level of probability. The results of the present study were obtained on various characteristics of growth, yield and yield attributing traits and quality parameters of BARI tomato 11.

Phosphorus had significant influence on the all parameter. The highest plant height (110.40 cm) and branch length plant^{-1} (27.17 cm) were produced by P_3 (40 kg P ha^{-1}) but the highest number of branch plant^{-1} (5.94), number of flower clusters plant^{-1} (12.35), number of flowers cluster^{-1} (27.49), number of fruits cluster^{-1} (20.69), number of fruits plant^{-1} (255.70), number of fruits plot^{-1} (1023.00), fruit weight plot^{-1} (7.03 kg) and fruit yield ha^{-1} (40.15 t) were achieved from the treatment P_2 (30 kg P ha^{-1}). The lowest plant height (103.30 cm), branch length plant^{-1} (24.47 cm), number of branch plant^{-1} (5.17), number of flower clusters plant^{-1} (11.93), number of flowers cluster^{-1} (24.08), number of fruits cluster^{-1} (17.78), number of fruits plant^{-1} (209.10), number of fruits plot^{-1} (836.30), fruit weight plot^{-1} (5.70 kg) and fruit yield ha^{-1} (32.58 t) was obtained from control treatment P_0 (0 kg P ha^{-1}).

All the above mentioned characters were also significantly influenced by sulphur application. However, branch length plant^{-1} did not vary significantly due to the effect of S. Results revealed that the highest plant (109.70 cm) and branch length plant^{-1} (25.67 cm) were recorded from S_3 (20 kg S ha^{-1}) but the highest number of branch plant^{-1} (6.05), number of flower clusters plant^{-1} (12.75), number of flowers cluster^{-1} (27.13), number of fruits cluster^{-1} (20.23), number of fruits plant^{-1} (253.40), number of fruits plot^{-1} (1014.00), fruit weight plot^{-1} (6.87 kg) and fruit yield ha^{-1} (39.23 t) were found from the treatment S_1 (10 kg S ha^{-1}) where the lowest plant height (105.10 cm), branch length plant^{-1} (25.37 cm), number of branch plant^{-1} (5.22), number of flower clusters plant^{-1} (10.78), number of flowers cluster^{-1} (23.87), number of fruits cluster^{-1} (19.83), number of fruits plant^{-1} (187.70), number of fruits plot^{-1} (750.90), fruit weight plot^{-1} (5.28 kg) and fruit yield ha^{-1} (30.17 t) were found from the control treatment S_0 (0 kg S ha^{-1}).

All the studied characters among the growth, yield and yield contributing were significantly affected by the combined effect of phosphorus and sulphur fertilizers whereas the combination of P_2S_1 (30 kg P ha^{-1} and 10 kg S ha^{-1}) performed best comparatively than that of other combinations. Results exposed that the highest plant height (117.00 cm) and branch length plant^{-1} (27.67 cm) were recorded from the treatment combination of P_3S_3. But the highest number of branch plant^{-1} (6.64), number of flower clusters plant^{-1} (13.03), number of flowers cluster^{-1} (30.07), number of fruits cluster^{-1} (22.10), number of fruits plant^{-1} (284.10), number of fruits plot^{-1} (1136.00), fruit weight plot^{-1} (7.63 kg) and fruit yield ha^{-1} (43.59 t) were recorded from the treatment combination of P_2S_1. Again, the The lowest plant height (97.99 cm), branch length plant^{-1} (22.85 cm), number of branch plant^{-1} (4.50), number of flower clusters plant^{-1} (9.93), number of flowers cluster^{-1} (23.21), number of fruits cluster^{-1} (17.13), number of fruits plant^{-1} (169.00), number of fruits plot^{-1} (676.00), fruit weight plot^{-1} (4.47 kg) and fruit yield ha^{-1} (25.51 t) was achieved from the treatment combination of P_0S_0.

The effect of different doses of phosphorus nutrient showed a statistically significant variation in the N, P and S concentration in post harvest plant shoot and root. The P_3 (40 kg P ha^{-1}) treatment showed the highest N concentration (2.54%), P concentration (0.825 ppm) and S concentration (1.06 ppm) in plant shoot. The treatment P_3 (40 kg P ha^{-1}) also showed the highest N concentration (2.37%), P concentration (0.905 ppm) and S concentration (1.145 ppm) in plant root. The lowest nutrient concentration in shoot and root, in terms of N concentration (1.50% and 1.41%, respectively), P concentration (0.275 ppm and 0.32 ppm, respectively) and S concentration (0.965 ppm and 1.04 ppm, respectively) were achieved from control treatment P_0 (0 kg P ha^{-1}). P had no significant effect on K concentration in plant shoot and root.

The effect of different doses of sulphur nutrient showed a statistically significant variation in the N, P and S concentration in post harvest plant shoot and root. In plant shoot and root, the treatment S_3 (20 kg S ha^{-1}) showed highest N concentration (2.46% and 2.24%, respectively), P concentration (0.62 ppm and 0.698 ppm, respectively) and S concentration (1.325 ppm and 1.413 ppm, respectively) where the lowest N concentration (1.68% and 1.53%, respectively), P concentration (0.523 ppm and 0.595 ppm, respectively) and S concentration (0.50 ppm and 0.57 ppm, respectively) were achieved from control treatment S_0 (0 kg S ha^{-1}). S had no significant effect on K concentration in plant shoot and root.

Combined effect of P and S had also significant effect on N, P and S concentration in post harvest plant shoot and root. The treatment combination of P_3S_3 showed the highest N concentration (2.72%) and P concentration (0.88 ppm) in plant shoot but the highest S concentration in plant shoot (1.38 ppm) was recorded in the treatment combination of P_0S_3 where the lowest N concentration (1.12%), P concentration (0.220 ppm) and S concentration (0.44 ppm) in plant shoot was found in P_0S_0. Again, the highest concentration of N (2.58%), P (0.95 ppm) and S (1.45 ppm) in plant root were recorded in the treatment combination of P_3S_3 where the lowest N concentration (1.02%), P concentration (0.25 ppm) and S concentration (0.48 ppm) in plant root were found in P_0S_0. K concentration in plant shoot and root was not significantly affected by combined effect of P and S.

Conclusion

Among the combination of different levels of phosphorus and sulphur nutrients, 30 kg P ha^{-1} and 10 kg S ha^{-1} induced superior growth, yield contributing characters and yield of BARI tomato 11. But phosphorus application at 40 kg ha^{-1} combined with sulphur at 20 kg ha^{-1} showed better performance on nutrient concentration in plant shoot and root.

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

1. Other doses of P and S need to be considered before final recommendation.
2. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability and other performance.

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APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location

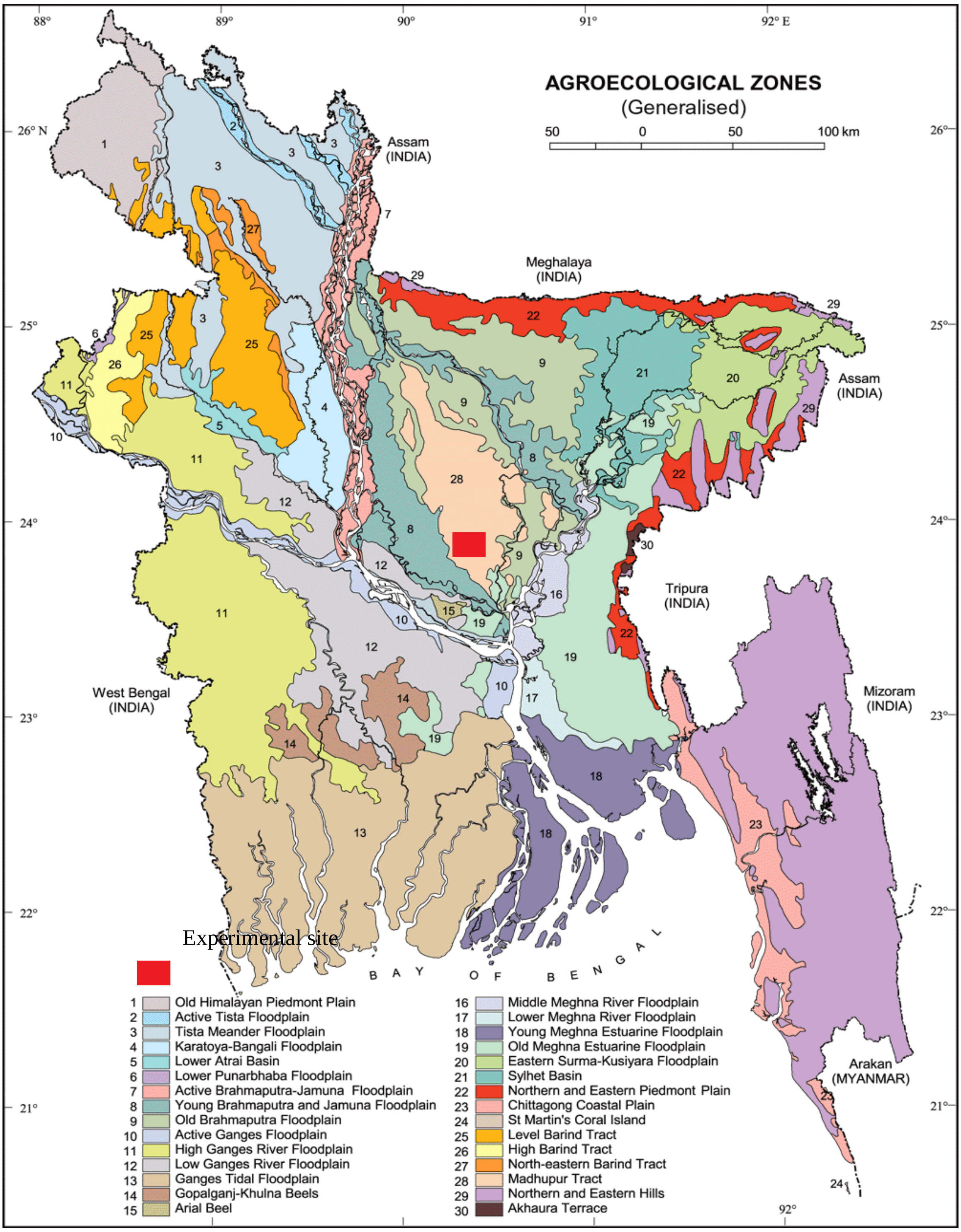

Fig. 7. Experimental site

Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from October 2017 to April 2018

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2017	October	30.42	16.24	23.33	68.48	52.60
2017	November	28.60	8.52	18.56	56.75	14.40
2017	December	25.50	6.70	16.10	54.80	0.0
2018	January	23.80	11.70	17.75	46.20	0.0
2018	February	22.75	14.26	18.51	37.90	0.0
2018	March	35.20	21.00	28.10	52.44	20.4
2018	April	34.70	24.60	29.65	65.40	165.0

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix III. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	Value
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI)

Appendix IV. Layout of the experiment field

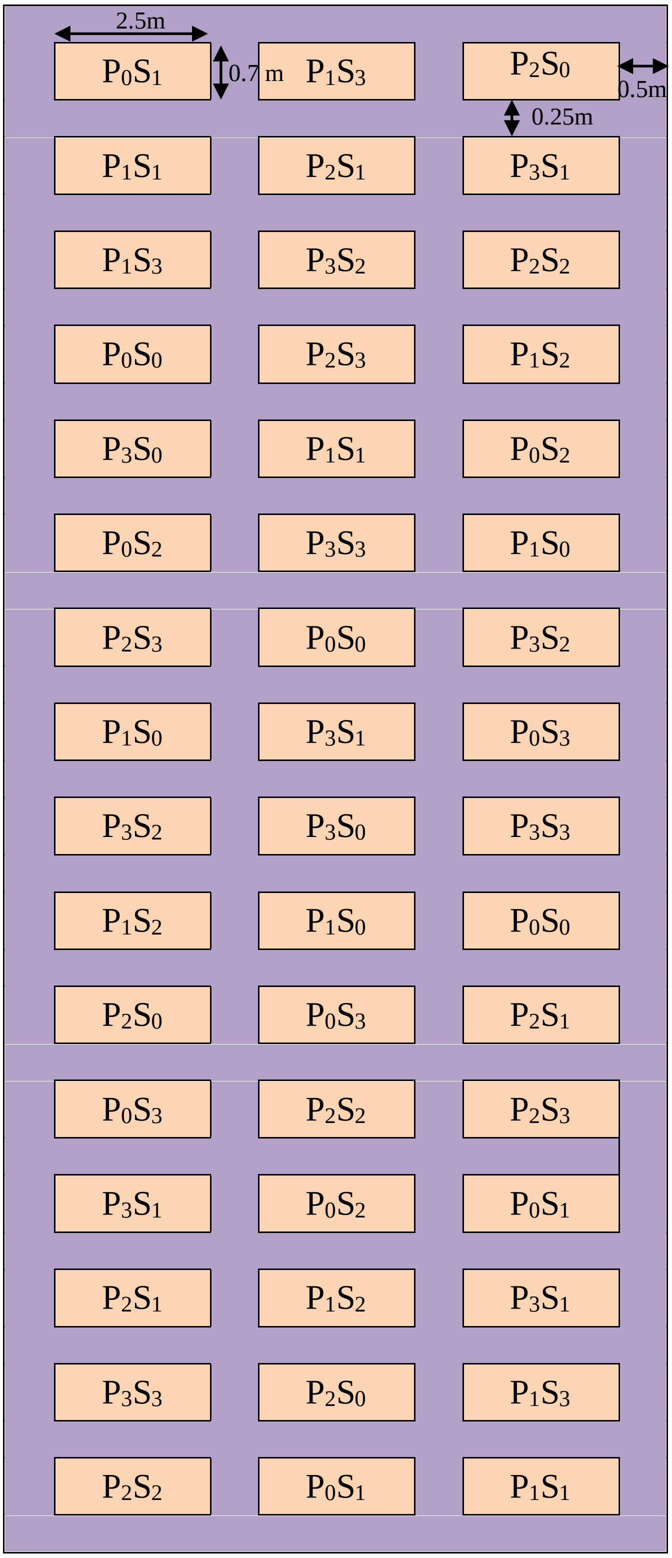

Fig. 8. Layout of the experimental plot

Appendix V. Effect of phosphorus and sulphur and also their combination on growth parameters of BARI tomato 11

Sources of variation	Degrees of freedom	Growth parameters at harvest		
		Plant height (cm)	Branch length $plant^{-1}$	Number of branches $plant^{-1}$
Replication	2	4.851	2.861	2.276
Factor A	3	131.14*	16.01*	1.254*
Factor B	3	45.025*	0.844 ^{NS}	1.544*
AB	9	35.432*	2.708*	1.446**
Error	30	7.93	4.209	0.837

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VI. Effect of phosphorus and sulphur and also their combination on yield contributing parameters of BARI tomato 11

Sources of variation	Degrees of freedom	Yield contributing parameters			
		Number of cluster $plant^{-1}$	Number of flowers $cluster^{-1}$	Number of fruits $cluster^{-1}$	Number of fruits $plant^{-1}$
Replication	2	3.013	2.435	5.617	16.082
Factor A	3	0.464**	23.768*	17.846*	489.453*
Factor B	3	10.508*	24.660*	20.192*	1255.47*
AB	9	0.516*	2.221**	1.552**	34.123*
Error	30	7.117	2.503	2.263	9.247

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VII. Effect of phosphorus and sulphur and also their combination on yield parameters of BARI tomato 11

Sources of variation	Degrees of freedom	Yield parameters		
		Number of fruits $plot^{-1}$	Fruit weight $plot^{-1}$ (kg)	Fruit yield ha^{-1} (t)
Replication	2	17.313	1.678	3.979
Factor A	3	782.250*	4.464*	146.070*
Factor B	3	2008.47*	6.658*	218.069*
AB	9	55.972*	0.138**	4.522*
Error	30	17.957	1.575	3.396

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VIII. Effect of phosphorus and sulphur and also their combination on nutrient concentration in shoot of BARI tomato 11

Sources of variation	Degrees of freedom	Nutrient concentration in shoot			
		N (%)	P (ppm)	K (ppm)	S (ppm)
Replication	2	0.090	0.021	0.001	0.027
Factor A	3	2.531*	0.767*	0.012 NS	0.030**
Factor B	3	1.342*	0.019**	0.001 NS	1.535*
AB	9	0.052**	0.005**	0.016 NS	0.009**
Error	30	0.013	0.003	0.002	0.002

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix IX. Effect of phosphorus and sulphur and also their combination on nutrient concentration in root of BARI tomato 11

Sources of variation	Degrees of freedom	Nutrient concentration in root			
		N (%)	P (ppm)	K (ppm)	S (ppm)
Replication	2	0.050	0.033	0.001	0.040
Factor A	3	2.072*	0.833*	0.004NS	0.034**
Factor B	3	1.183*	0.022**	0.011 NS	1.634**
AB	9	0.048**	0.003**	0.003 NS	0.006**
Error	30	0.003	0.001	0.001	0.002

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level