EFFECTS OF POTASSIUM AND SULPHUR ON THE GROWTH, YIELD, PROTEIN AND OIL CONTENT OF SOYBEAN (*Glycine max* L.)

By

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This is to certify that thesis entitled, "*EFFECTS OF POTASSIUM AND SULPHUR ON THE GROWTH, YIELD, PROTEIN AND OIL CONTENT OF SOYBEAN*" 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 (M.S.)* in *AGRICULTURAL CHEMISTRY* embodies the result of a piece of *bona fide* research work carried out by *MOHAMMAD TIPU SULTAN, Registration No. 05-1648* under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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Dedicated to

My

Beloved Parents

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ABSTRACT

A field experiment was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka 1207 during the period from December 2011 to April 2012 to study the effects of potassium and sulphur on the growth, yield, protein and oil content of soybean (*Glycine max* var.BARI Soybean 5). The experimental soil was clay loam in texture having pH of 6.6. The experiment included four levels of potassium viz., 0, 20, 40 and 60 kg K ha^{-1} and four levels of sulphur viz., 0, 10, 20 and 30 kg S ha^{-1}. The experiment was laid out in a Randomized Complete Block Design with three replications. Potassium showed significant effect on yield and yield attributes of soybean. Application of potassium @ 40 kg ha^{-1} produced the highest seed yield, plant height, number of primary branches $plant^{-1}$, number of leaves $plant^{-1}$, number of pods $plant^{-1}$, number of seeds $plant^{-1}$, 1000-seed weight and straw yield. In all the cases lower response was found from the control treatment. Sulphur fertilizer also had significant effect on yield and yield attributes of soybean. Application of sulphur @ 20 kg ha^{-1} produced the highest seed yield, plant height, number of primary branches $plant^{-1}$, number of leaves $plant^{-1}$, number of pods $plant^{-1}$, number of seeds $plant^{-1}$, 1000-seed weight and straw yield but in all the cases the lower response was found from the control treatment. Potassium in combination with sulphur showed significant effect on yield and yield attributes of soybean. The combination of potassium and sulphur @ 40 Kg K and 20 kg S ha^{-1} gave the highest seed yield, number of primary branches $plant^{-1}$, number of leaves $plant^{-1}$, number of pods $plant^{-1}$, number of seeds $plant^{-1}$, 1000-seed weight, protein and oil contents of soybean except plant height. The highest plant height was observed with the application of potassium @ 60 kg ha^{-1} and sulphur @ 20 kg ha^{-1}. On the other hand, in all the cases the lower response was found from the control treatment.

LIST OF ABBREVIATIONS

ABBREVIATION	FULL WORD
%	Percent
@	At the rate of
^0C	Degree Celsius
AEZ	Agro-Ecological Zone
cm	Centimeter
$CuSO_4.5H_2O$	Green vitriol
CV%	Percentage of Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
DMRT	Duncan's Multiple Range Test
e.g.	As for example
et al.	and others
g	Gram
i.e.	that is
kg	Kilogram
kg ha^{-1}	kg per hectare
LSD	Least Significant Difference
m	Meter
MP	Muriate of Potash
OM	Organic matter
RCBD	Randomized Complete Block Design
SAU	Sher-e-Bangla Agricultural University
t ha^{-1}	Ton per hectare
TSP	Triple Super Phosphate

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Introduction

Chapter 1

INTRODUCTION

The soybean (***Glycine max L.***) is a species of legume native to East Asia, widely grown for its edible bean which has numerous uses. The plant is classed as an oilseed rather than a pulse by the UN Food and Agricultural Organization (FAO). Soybeans are an important global crop, providing oil and protein. The average worldwide yield for soybean crops, in 2010, was 2.5 tonnes per hectare (FAO, 2010). The three largest producers had average nationwide soybean crop yields of about 3 tonnes per hectare. The most productive soybean farms in the world in 2010 were in Turkey, with a nationwide average farm yield of 3.7 tonnes per hectare. As a grain legume crop it is gaining an important position in the agriculture of tropical countries including India, Sri Lanka, Thailand and Bangladesh.

Soybean as a crop was introduced into Bangladesh during the 1960s and beginning in the early 1980s, cultivation was promoted by the Mennonite Central Committee [MCC], an international voluntary organization working in Bangladesh. Largely as a result of MCC efforts, cultivation expanded somewhat, especially in the Noakhali area. Today, approximately 90,000 acres is under soybean cultivation and the production is approximate 100,000 ton a year (BARI, 2011). This figure is growing because of the demand for locally-grown soybeans in the animal feed industry. For a variety of reasons, it is thought that Bangladesh could become a major producer or a producer able to meet its own growing requirements for soybeans and soybean products.

Soybean contains higher amounts of oil and protein than any other legume crops. Soybean is a good source of protein, unsaturated fatty acids, minerals like Ca and P including vitamin A, B, C and D (Rahman, 1982). Furthermore, soybean oil is cholesterol free. On an average, about 8-10% of the protein intake in Bangladesh diet originates from animal sources (Begum, 1989) and the rest can be met from plant sources especially from the pulse crops like soybean.

Acute shortage of edible oil has been prevailing in Bangladesh during the last several decades. This shortage has inherited from the past. In 1972-73, its production was only 54.6 thousand tons that could meet only 30% of the requirement of the 75 million people leaving a shortage of 70%. At that time, there was no high yielding variety (HYV) or improved technology of oilseeds.

Oils and fats play an important role in human nutrition. As a high energy component of food, edible oil is important for meeting the calorie requirement. This is also important for improving the taste of a number of food items. Oil/fat supplies energy and it provides double the quantity of energy than the same quantity of protein or carbohydrate. Fats and oils act as carrier for fat soluble vitamins (A, D, E and K) in the body and therefore, the presence of some fats/oils in the diet is essential for their absorption. Fats and oils are also the sources of essential fatty acids. The main essential fatty acids of vegetable oils are linoleic and linolenic acids. Fats and oils are used to synthesize phospholipids which are important component of active tissues viz. brain, nerve and liver of human being and other animals. In Bangladesh, sources of edible oils are rapeseed/mustard, sesame, groundnut, soybean, niger, linseed, sunflower and safflower. Although linseed is not considered as edible oil, but its seed is mixed with mustard and sesame to extract oil and is being used for edible purposes. Nevertheless, linseed and castor oils are used as valuable industrial oils. Soybean is being cultivated in Bangladesh since long but the present production is not sufficient enough to extract oil profitably. In Bangladesh, soybean is not yet popular as a crop but soybean oil is very popular as cooking oil. Its seed contain 42-45% best quality protein and 20-22% edible oil (Wahhab *et al.,* 2001). However, soybean is an important source of good quality protein and oil and can play an important role in solving the malnutrition problem of Bangladesh.

Soybean, like many other legumes, is capable to fix and utilize atmospheric nitrogen through a symbiotic relationship with *Rhizobium japonicum. Rhizobia* are minor component of the soil micro flora, and while not restricted to rhizosphere soil, reach their maximum numbers in association with plant roots (Reicosky *et al.,* 1985).

Fertilizers have been used in most countries where agriculture is now well developed but their essential role in modern farming has become clear only in the last 60 years. Due to the cultivation of modern varieties of different crops with unbalanced and heavy use of fertilizers, soil toxicity/ pollution are arising and soils of Bangladesh are losing their fertility and productivity.

Potassium is one of the three major essential nutrient elements required by plants. Unlike nitrogen and phosphorus, potassium does not form bonds with carbon or oxygen, so it never becomes a part of protein and other organic compounds (Hoeft *et al.,* 2000). Although K is not a constituent of any plant structures or compounds, it is involved in nearly all processes needed to sustain the plant life. Potassium in cell sap is involved in enzyme activation, photosynthesis, transport of sugars, protein and starch synthesis. It is also known for its role to provide lodging resistance and insect/disease resistance to plants. Potassium exists in mobile ionic form (K^+) and its function appears to be primarily catalytic in nature. Plants absorb K in larger amounts than any nutrient except N. K has beneficial effect on symbiotic N-fixation by leguminous plants. High K supply has increased nodule mass, N-fixation rate, nitrogenase activity and growth of soybean. K deficiencies greatly reduce the quality and crop yields. Serious yield reduction may occur without the appearance of deficiency symptoms. This phenomenon is known as "hidden hunger" and this phenomenon occurs not only for K but also for other elements.

Sulphur is being recognized as the 4th major plant nutrient after N, P, K. Crop in general require as much S as they need P. Soils which are deficient in S cannot support successful plant growth. S application is a must for proper growth, yield and oil content of soybean. Most soil sources of S are in the organic matter and are therefore concentrated in the topsoil or plough layer. Elemental S and other forms as found in soil organic matter and some fertilizers, are not available to crops. They must be converted to the sulfate (SO_4^{2-}) form to become available to the crop. This conversion is performed by soil microbes and therefore requires soil conditions that are warm, moist, and well drained to proceed rapidly. The sulfate form of S is an anion (negative charge), and therefore is leachable. As a rough rule-of-thumb, it can be considered to leach through the soil profile at about 50% as fast as nitrates (NO_3^-). In soils with a significant and restrictive clay layer in the sub-soil, it is common to find that sulfate which has leached through the soil over time and become "perched" on the clay layer. This SO_4^{2-} is available to crops when the roots reach this area of the soil. Sulfur is a necessary constituent in several amino acids and proteins. S is also needed for the synthesis of other metabolites, including coenzyme A, biotin, thiamin or vitamin B_1 and glutathione. It occurs in volatile compounds responsible for the characteristic taste and smell of plants in the mustard and onion families. S stimulates seed formation and promotes nodule formation on the roots of leguminous plants. Since these are building blocks in the plant, Sulfur becomes fixed into the plant's structure. Therefore, the classic symptom of deficiency is a paleness of the younger foliage. However, many times all of the foliage has a pale green color, and the difference in "paleness" between the older and younger foliage is not easily noticed. This can lead to a misdiagnosis of N deficiency for S deficiency (*Nitrogen deficiency symptoms appear on the older leaves first.*). In some cases, the leaf veins may be lighter in color than the surrounding tissue.

In Bangladesh, limited information is available on the effects of potassium and sulphur on the growth, yield and oil content of soybean. With a view to generate information a field experiment containing the treatments of each of potassium and sulphur was conducted with the following objectives:

1. To compare the growth and yield performance of soybean by using different doses of potassium and sulphur.
2. To observe the interaction effects of K and S on the growth, yield, protein and oil content of soybean.
3. To find out the optimum doses of K and S for maximum growth, yield, protein and oil content of soybean.

Chapter 2
Review of Literature

Chapter 2

REVIEW OF LITERATURE

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

2.1 Effect and importance of Potassium application on soybean

Potassium enters in plant as K^+ and remains in plant in ionic form. A small fraction of it is found absorbed by protein in active leaves to cater to many enzymatic reactions and this form is not extractable by water. It is essential for reactions in using high-energy phosphates (adenosine phosphates), in first reaction in photosynthesis in using the captured light energy to convert adenosine diphosphate (ADP) and phosphate into adenosine triphosphate (ATP) in the synthesis of amino-acids. Potassium in soil solution is in equilibrium with exchangeable potassium on clay minerals and humus. Potassium moves in soil by diffusion process and hence is not as easily available to plants as nitrogen. It does not get lost from the soil as nitrogen does. It moves from older leaves to younger leaves. Therefore, the older leaves are the first to show deficiency symptoms.

Young seedlings of soybean do not use much potassium, but the rate of uptake climbs to a peak during the period of rapid vegetative growth. The potassium in vegetative parts is transferred to seed during pod fill process. The mature soybean seed contains nearly 60% of the total K in plant (Hoeft *et al.,* 2000). It is to be noted that on weight basis, soybean seed contains more than twice as much potassium as corn grain. Deficiency symptoms, if those are going to appear in soybean, will be seen during the period from late flowering to early seed fill. The potassium concentration in soybean plants decreases near maturity. Any deficit of K during the late vegetative and reproductive stages is going to reflect on yield of soybean. K-uptake in soybean has been estimated at about 101-120 kg/ha K (Nambiar and Ghosh, 1984 and Aulakh *et al.,* 1983). Similar removal of 101 kg/ha of K has been reported in case of soybean in Madhya Prodesh *i.e.*India state by Swarup *et al.* (2001). Soils high in K may not pose any problem but those low in available K shall need building up of K during the period when it is needed most. In general, the soybean is grown in semi-arid regions, particularly vertisols and associated soils and these soils are rich in potassium.

Swarup *et al.* (2001) have reported an overall negative balance of potassium in Madhya Prodesh *i.e.*India state, which was highest in Malwa plateau, the home of soybean. With the introduction of improved high yielding varieties and intensive agriculture, it is imperative to standardize and readjust the recommendation for potassium for sustainable soybean-based cropping systems. The revision of K levels are further needed in view of lower fertilizer use efficiency of K (20-40%) than that of N (above 40%) for soybean and corn (Carpenter, 1975) and major movement of the element in soil to plant roots by diffusion and lesser contribution of root hairs in K uptake as compared to phosphorus (Mengel and Barber, 1974).

The results of experimentation on the effect of application of different combinations of NPK on the performance of soybean in black cotton soils of Akola during *'kharif'* season revealed improvement in yield attributing characters, yield and quality (oil and protein content) of soybean with increasing levels of NPK (Nagre *et al.,* 1991). It is difficult to work out the individual share of potassium in this study, but the contribution of potassium in the overall response can be well accepted.

Based on the agronomic experimentation in different agro-climatic regions, the All India Coordinated Research Project on Soybean has recommended application of nitrogen, phosphorus, potassium and sulphur at the levels of 20 kg N/ha, 26.0-34.6 kg P/ha, 16.6 -33.2 kg K/ha and 20 kg S/ha, keeping in view the adjustment based on soil test values. The reported crop uptake of these nutrients was 125-190 kg/ha of N, 19-43 kg/ha of P, 101-120 kg/ha of K and 9-22 kg/ha of S (Nambiar and Ghosh, 1984; Aulakh *et al.,* 1983). A similar report for K removal in Madhya Prodesh *i.e.*India was made by Swarup *et al.* (2001). Vedprakash *et al.* (2001) found that values of net depletion of K (sum total of available and non exchangeable K) from soil profile after 27 cropping cycles of soybean-wheat were quantitatively much higher than the expected K depletion values (based on K input-output balance sheet) suggesting considerable loss of K from soil profiles. Consistently higher rainfall during the rainy season could be attributed to cause K loss through leaching. Recommendation of 20 kg N/ha as starter dose is well justified. It is capable of meeting the nitrogen requirement as the soybean crop has been reported to fix atmospheric nitrogen to the extent of 50 to 300 kg/ha (Keyser and Li, 1992), which is further supplemented by biomass recycling and non-symbiotic fixation. Recommendation of phosphorus and sulphur also matches the respective nutrient uptake. There appears to be a wide gap between the recommendations of potassium application vis-à-vis its uptake. This fact was probably uncared for on account of richness of vertisols and associate soils in K. By and large, no potassium is applied by farmers in the major soybean growing areas.

The long-term experimentation conducted on vertisols of Jabalpur (Madhya Prodesh *i.e.* India) in soybean-wheat-maize fodder revealed that not only the yield of soybean was increased by 6%, but application of potassium at recommended levels also enhanced the uptake of major, secondary and some of the micronutrients (Swarup *et al.*, 2001).

Soybean is not especially sensitive to magnesium deficiency. Research has not supported the claim that high potassium will reduce yield by inducing a shortage of magnesium (Hoeft *et al.*, 2000).

Anuradha and Sharma (1995) found that the application of potassium increased the chlorophyll content, nitrate reductase activity, seed protein and oil content in soybean.

Deshmukh *et al.* (1994) obtained the highest soybean yield and oil content with an application of 60 kg K_2O/ha at Amravati and 90 kg K_2O/ha at Akola in Maharashtra State. More conclusive results on yield responses of soybean were obtained in experimentation organized by International Potash Institute for three years at Amlaha (Mouddha Prodesh *i.e.* India) on vertisols by Magen (1997) where increased seed yield, oil and protein contents and nodulation was observed. The results have clearly brought out that the responses of K application on vertisols (having 112 ppm of available K) can be obtained up to 100 kg K_2O/ha. The split application at 35 days after sowing was still superior in obtaining response. The results offer reconsideration of recommended level of potassium application *i.e.* 20 kg K_2O/ha. In addition to above responses, resistance of plants against major insect-pests of soybean *i.e.* girdle beetle, semilooper and aphid attack was also realized based on pooled data for three years (Magen, 1997).

In case of intercropping, not much information is available. However, Hegazy and Genaidy (1995) reported that the application of potassium sulphate improved the growth of soybean when either mono or intercropped on clayey soil. The relative K fertilizer efficiencies were reduced in intercropping compared to monocropping thereby increasing the economic optimum K fertilizer rates.

Dixit and Sharma (1993) reported that soybean seed yield increased following application of up to 12.5 kg K in silty loam soils of Palampur (Himachal Pradesh). Application of K also increased uptake of N, P and K. Unlike the results obtained at Jabalpur , the application of K decreased Ca and Mg uptake in these acid soils.

Although the major soybean area is on Vertisols and associated soils, the crop is cultivated and is further extending to other soil types as well. Significant responses of supplementation of K have been observed in other soils also. Normally crop responds to the application of nutrients in soils, which are low to medium in K. The researches done at Iowa (USA) revealed that there have been frequent significant yield increases in soybean in the soils with medium soil test potassium values (68 to 100 ppm) on account of K applications (Mallarino *et al.,* 1991). Although, no response of K application up to 75 kg K_2O/ha was obtained on Laterites of Maharashtra (Talathi, 1983), response of K application in alluvial tract of Uttar Pradesh in the farmers' field (32 trials) was obtained up to 60 kg K_2O/ ha. Maximum response (56%) was obtained with $N_{20}P_{40}K_{20}$ over $N_{20}P_{40}K_0$, which decreased by increasing the levels of all the three nutrient elements.

The results of green house study showed that the soybean yielded highest with 27.75 ppm K in all types of soil (Singh *et al.,* 1993). On loamy sand soil, split application of potassium was found beneficial than applying full dose at the time of planting. Soybean responded significantly up to 50 kg K_2O/ha when applied 50% at planting and 50% at flower initiation (two splits) or 1/3 at planting, 1/3 at flower initiation and 1/3 at pod development (three splits). The percent agronomic efficiency, percent physiological efficiency and percent apparent K recovery reduced as the rate of applied K was increased from 50 to 75 kg K_2O/ha.

Grewal *et al.* (1994) observed that the soybean seed yield increased following application of up to 50 kg K_2O/ha when N was applied and up to 25 kg K_2O/ha in the absence of N in loamy sand soils of Punjab.

Rajagopal and Velu (1995) observed that the soybean responded to application of only up to 40 kg K_2O/ha and the magnitude of response was higher in *'kharif'* than *'rabi'* season.

Application of 80 kg K_2O/ha with either 20 or 40 kg N/ha significantly increased the yield and yield attributes in sole and intercropping systems in sandy loam soils (Mandal and Pramanik, 1996).

Application of 30 kg K_2O/ha or N x K interaction significantly increased the nodule number and yield attributes (Singh *et al.,* 1999). The application of N, P and K individually also increased the seed yield of soybean.

On sandy clay loam soil, Annadurai *et al.* (1994) observed that the application of 40 kg K_2O increased the soybean seed yield and oil content.

A long-term experiment was conducted in shallow sandy loam soil of Hawalbagh Farm, Almora (Uttranchal) with an application of 33.2 kg K/ha in combination with N, P and farm-yard manure in soybean-wheat cropping sequence (Ghosh *et al.*, 1998; Kundu *et al.*, 1990). It indicated the beneficial role of K in enhancing yield stability of soybean under rainfed condition. A gradual increase in K response was obtained with the increase in advancing years of cultivation from 1973 to 1997. The average response of soybean was 18.76 kg grain/kg K. The net depletion of K over years was high.

Habibzadeh *et al.* (2004) revealed that the highest yield (2062.5 kg/ha) and 1000-seed weight (90.6 g) were obtained with 225 kg K/ha, however, there was no significant difference between 75, 150 and 225 kg K/ha on yield. There was no significant difference between 150 and 225 kg K/ha for 1000-seed weight. The K at 75, 150 and 225 kg K/ha significantly increased the number of pods per plant, but there was no significant difference among the application rate.

Field experiments were conducted to investigate the effects of doses and split applications of potassium on two soybean cultivars (Garimpo and Ft-Cristalina) planted on Eutric Red Latosol, sandy-textured cerrado soil of Minas Gerais, Brazil in 1999/2000 agricultural year. Potassium was applied during planting (P), covering (C) and budding (F) period of soybean. The following rates of K were applied at the planting time: 0, 30, 60 and 90 kg K_2O/ha. In another experiment, 60 kg K_2O/ha was applied at different times of crop developing: 00P-60C-00F; 20P-40C-00F; 30P-30C-00F; 40P-20C-00F; 00P-00C-60F; 20P-00C-40F; 30P-00C-30F; 40P-00C-20F and 60P-00C-00F (control). A significant quadratic increase up to 90 kg K_2O/ha resulted to a higher yield, plant height, height of insertion of the first seedpod and K in the soil. The application of 60 kg K_2O/ha at budding stage resulted to an increase in the number of seed, pods per plant, number of plants per plot unit and minor number of seeds (Hungria and Franchini, 2000).

Singh and Singh (1995) conducted a field experiment on a sandy-loam soil during the rainy seasons of 1989-90 at Kanpur, Uttar Pradesh, soybeans cv. Gaurav were given 0, 40, 80 or 120 kg K_2O, 0 or 20 kg zinc oxide and 0 or 30 kg S/ha. K and S applications increased seed yields in both years while Zn application increased yield in 1989 only. Seed yield and net return were the highest with 120 kg K_2O in 1989. In field experiments at Alma, Arkansas with soybeans cv. Pioneer 9591 in 1990, Williams 82 in 1991 and Pioneer 9391 in 1992, row spacing and K application did not significantly affect seed yields.

Soybean response to K fertilizer was studied over a 5-year period on a dystrophic Oxisol with very low exchangeable K in Brazil. K was applied annually at 0-200 kg K_2O/ha. There was a response to K when exchangeable soil K was below 40 mg K/kg soil. Borkert and Yamada (2000) reported that application rates over 80 kg K_2O/ha was required for high yields and to correct the soil K level after 5 years of experimentation. Seed K concentration increased with higher K rate, and over 80 kg/ha was required to give the desired seed concentration of at least 12 g K/kg seed.

Mondal *et al*. (2001) conducted a field experiment during *kharif* 1999-2000 in Parbhani, Maharashtra, India, to investigate the response of soybean grown on

Vertisol to different rates of nitrogen, phosphorus and potassium (0, 30, 60 and 90 kg, N, P_2O_5 and K_2O/ha, respectively). Results showed that N and P_2O_5 at 90 kg/ha showed the highest yield for pods per plant, 100 seed weight, crude protein, seed and straw yields. Potassium application did not affect any of the yield components. The interaction effect of the different treatment combinations were non-significant except crude protein which was significantly increased up to 40.52% with N and P_2O_5 at 90 kg/ha.

2.2 Effect and importance of Sulphur fertilizers on Soybean

Singh *et al.* (2001) conducted a field experiment in New Delhi, India to assess the growth characteristics, seed and oil yield of two cultivars of soybean (G. max), i.e. PK-416 (V_1) and PK-1024 (V_2), in relation to sulfur and nitrogen nutrition. Six combinations (T_1-T_6) of two levels of sulfur (0 and 40 kg ha^{-1}) and two levels of nitrogen (23.5 and 43.5 kg ha^{-1}) were applied to the two soybean cultivars as nutrients. Results indicated significant effect of sulfur and nitrogen, when applied together, on the growth characteristics, yield components, and seed and oil yield. Maximum response was observed with treatment T_6 (having 40 kg S and 43.5 kg N ha^{-1}). Seed and oil yields were increased by 90 and 102% in V_1, and 104 and 123% in V_2, respectively, compared to the control i.e. T_1 (having 0 kg S and 23.5 kg N ha^{-1}). Positive responses of S and N interaction on leaf area index, leaf area duration, crop growth rate and biomass production were also observed. The results obtained in these experiments clearly suggest that balanced and judicious application of nitrogen and sulfur can improve both seed and oil yield of soybean cultivars by enhancing their growth.

A pot culture experiment was carried out with soybean in 2001 in a glasshouse on a clay loam soil deficient in available S. The treatments consisted of four levels of S (0, 7.5, 15, 30 kg ha^{-1}) supplied through gypsum in the presence and absence of *Bradyrhizobium* inoculation. Vijayapriya and Muthukkaruppan (2005) reported that nutrient uptake and availability of nutrients were significantly influenced by the addition of S and *Rhizobium* compared to the control. The nutrient uptake and availability were significantly higher in plants inoculated with *Rhizobium* compared to uninoculated plants. The uptake of N, P, K and S by soybean and their availability in soil increased with S levels and the highest values were recorded at 30 kg S ha^{-1}.

A pot culture experiment was conducted on a clay loam soil in Annamalainagar, Tamil Nadu, India, during 2001 to investigate the effect of S (at 0, 7.5, 15 and 30 kg/ha), with and without *Bradyrhizobium* inoculation on the growth and yield of soybean. Soybean responded significantly in the presence of *Bradyrhizobium* and S compared to the control. Sriramchandrasekharan and Muthukkaruppan (2004) reported that plant height, root length, shoot and dry weights, number of pods per plant, 100-seed weight and seed yield were highest with 30 kg S/ha in the presence of *Bradyrhizobium* inoculation compared to S or inoculation alone and the control. The percentage increase in seed yield was 44 over the control. *Bradyrhizobium*-inoculated soil recorded higher rhizospheric microbial population compared to the uninoculated soil. S application significantly increased the bacterial population, while fungal population was higher in the control.

Sangale and Sonar (2004) conducted a field experiment during *kharif* 2003/04 to investigate the effects of S fertilizer sources (single super phosphate, elemental S and gypsum) and levels (0,10 and 20 kg/ha) on the seed yield, quality and S uptake of soybean cv. JS 335 grown on deep black soil in the Marathwada region of Maharashtra, India. Gypsum and single super phosphate were given at the time of sowing whereas elemental S was applied 15 days before sowing. Application of S at 20 kg/ha gave highest yield.

Mohanti *et al*. (2004) conducted a field experiment during *kharif* 2003-2004 at Raipur, Chhattisgarh, India to evaluate the effects of different levels of S (0, 10, 20 and 30 kg/ha) and B (0 and 0.002% at pre-flowering or pre-podding) on soybean cv. JS-335. Data were recorded for plant height, number of branches per plant, dry matter accumulation, test weight, harvest index and seed yield. S at 30 kg/ha recorded the highest values for these parameters. B and its interaction with S had no significant effect. Net realization per investment was highest with S at 20 kg/ha, followed by S at 30 kg/ha.

A pot culture experiment was conducted at a glasshouse in the Department of Agricultural Microbiology, Tamil Nadu, India, on a clay loam soil different in available sulfur. The treatments consisted of four levels of S (0, 7.5, 15 and 30 kg/ha) in the presence and absence of *Bradyrhizobium.* Arunageeta and Senthilkumar (2006) revealed that the highest soybean nodule number per plant (40.7), nitrogenase activity (579.8 nanomoles C_2H_4 nodules/h), number of pods per plant (51.7), seed yield (2295 g/pot), uptake of N (13 g/plant) and S (0.46 g/plant) were recorded with 30 kg S/ha. Similarly, *Rhizobium* inoculated plant recorded higher BNF, seed yield and uptake than uninoculated plants.

Gokhale *et al*. (2005) conducted a field experiment to study the effect of different sulfur (S) levels (0, 10, 20, 30, 40 and 50 kg/ha) on soybean (cv. MACS 124) in Maharashtra, India during *kharif* 2003-2004. Application of increasing S levels up to 30 kg/ha increased the seed yields over the control. Thus, the highest soybean yield of 25.1 q/ha was observed at 30 kg S/ha. Treatments with 40 and 50 kg S/ha slightly reduced the yields as the soil under study was marginally low in S content (9.6 mg/kg) which showed responses to lower S levels. The highest increase in monetary returns over the control (without S) was Rs. 4290/ha under the 30 kg S/ha treatment. Each level of S application up to 30 kg/ha significantly increased the uptake over the lower levels. The highest N and S uptake by seeds were observed at 30 kg S/ha (181.0 and 41.3 kg/ha, respectively) and higher levels of 40 and 50 kg S/ha slightly reduced the uptake. S application increased N and S availability in soil. Proteins and oil contents in soybean increased with increasing S levels up to 30 kg/ha. Thereafter, 40 and 50 kg S/ha showed a declining trend. Available N and S contents in the soil also increased (although only to a small extent) with increasing S levels applied to soybean.

A pot culture experiment was conducted by Praharaj and Dhingra (2003) using a clay loam soil to investigate the effect of S application *and Bradyrhizobium japonicum* inoculation on nodulation, nitrogenase activity and yield of soyabean cv. CO1. Sulfur was applied at 0, 7.5, 15.0 and 30.0 kg/ha through gypsum with or without *B. japonicum* inoculation. With increasing levels of S, there was gradual increase in nodulation, nitrogenase activity and seed yield. *B. japonicum* inoculation, irrespective of S levels, enhanced biological nitrogen fixation over uninoculated control, thereby increasing the seed yield of soybean significantly by 22%.

A field experiment was conducted by Tomar *et al.*(2000) at College of Agriculture, Indore, Madhya Pradesh, India, during the *kharif* seasons of 1998 and 1999, on medium black clay soil to study the effect of various levels and sources of sulfur on yield and biochemical composition of soybean cv. JS 335. The treatments comprised 5 S levels (10, 20, 30, 40 and 50 kg/ha) and 3 sources, i.e. gypsum, pyrite and elemental sulfur, along with an absolute control. Tomar *et al.* (2000) also reported that the highest seed yield, protein and oil content of 2257 kg/ha, 41.29% and 20.51%, respectively, were recorded with the application of 50 kg S/ha regardless of sources. Amongst different sources, gypsum proved the most effective followed by agricultural pyrites and elemental sulfur.

Mohan and Sharma (1991) observed that S @ 75 kg ha^{-1} significantly increased primary and secondary branches $plant^{-1}$. Sulphur @ 50 kg ha^{-1} increased the plant height significantly.

Saran and Giri (1990) reported from a couple of experiments that branches $plant^{-1}$ significantly increased with 60 kg ha^{-1} of S. Number of pods influenced the plant growth and attributes. They found that height and primary branches $plant^{-1}$, number of seeds $plant^{-1}$, number of leaves $plant^{-1}$and 1000 seed weight were also increased significantly with 60 kg ha^{-1} of S and seed weight/plant increased with 30 kg/ ha of sulphur.

2.3 Interaction effect of potassium and sulphur on Soybean

Soybeans cv. PKV-1 grown at Nagpur, Maharashtra in 1994/95 were given 0, 25, 50 or 75 kg K_2O and 0, 20 or 40 kg S/ha. Seed number/pod, 1000-seed weight, seed yield, harvest index and oil and protein concentrations are tabulated. The best combination of yield and quality was given by 50 kg K_2O and 40 kg S (Singh and Singh, 1995).

Soybeans grown at Nagpur, Maharashtra in the 1994/95 *kharif* [monsoon] season were given 0, 25, 50 or 75 kg K_2O and 0, 20 or 40 kg S/ha. Growth and yield per plant increased significantly with up to 25 kg K_2O and 40 kg S (Potkile and Bobde, 1996).

A pot culture experiment was conducted in sandy loam soil (pH 5.3) of Assam, India, to study the effects of K and S on nutrient availability, nutrient uptake and yield of soybean (cv. JS-2). The addition of graded levels of K fertilizer increased the availability of N, P, K and Ca in the soil at all the stages of crop growth, whereas S application significantly decreased the exchangeable Ca at 30 and 60 days after sowing and had no significant influence on the availability of N, P and K in the soil (Das *et al*., 2001). The application of K and S tended to increase nutrient uptake as reflected in the yield and yield attributes. The interaction effects of K x S were significant only for the number of pods per plant, 100-seed weight, grain and stover yields, and N-uptake by the grain.

Studies to evaluate the effect of S and K fertilizer application on Zn, Mn, Fe, and Cu in soybean in Vertisols of Madhya Pradesh, India revealed that the successive application of S significantly increased the contents of micro nutrients at all stages of growth up to 50 mg/kg compared with the control (Kadamdhad *et al*., 1996). On the other hand, a deleterious effect with successive K application was found on Zn, Fe, and Cu concentration in plant parts. The study also showed that Zn and Cu were readily mobile in the plant parts, whereas the movement of Fe and Mn was restricted. The content of micronutrients was higher in early stage but decreased with advancement of age. The maximum contents accumulated in the seed with a concomitant decrease in the straw at senescence. S and K application exhibited a synergistic relationship for soybean especially that grown on S- and K-deficient soil.
A field experiment was conducted during *kharif* 1998 at Akola, Maharashtra, India to investigate the effects to different levels of sulfur (S) and potassium (K) on the quality and nutrient uptake of soybean. Wasmatkar *et al*. (2001) reported that S at 15 kg ha^{-1} and K at 40 kg ha^{-1} gave the highest grain yields of 1962 and 1955 kg ha^{-1}, respectively. S at 30 kg ha^{-1} and K at 40 kg ha^{-1} recorded the highest straw yields of 1940 and 2060 kg ha^{-1}, respectively. S and K had significant effects on the uptake of N, P, K, S and Zn at harvest. The highest uptake of N (124.02 and 128.25 kg ha^{-1}) was recorded with S at 15 kg ha^{-1} and K at 40 kg ha^{-1}, respectively. The highest uptake of P (14.71 and 14.31 kg ha^{-1}), K (59.15 and 58.35 kg ha^{-1}), S (12.03 and 10.75 kg ha^{-1}) and Zn (108.23 and 101.43 kg ha^{-1}) was recorded with S at 30 kg ha^{-1} and K at 40 kg ha^{-1}, respectively. The same treatments recorded the highest contents of oil (21.03 and 20.62 %) and protein (37.47 and 37.37%) in soybean.

Chapter 3
Materials and Methods

Chapter 3

MATERIALS AND METHODS

This chapter includes a brief description of the experimental soil, soybean variety, land preparation, experimental design, treatments, cultural operations, collection of soil and plant samples etc. and analytical methods followed in the experiment to study the role of K and S on the growth, yield and oil content of soybean.

3.1 Experimental site

The research work relating to the study of the role of K and S on the growth, yield, protein and oil content of soybean was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka 1207 during the *Rabi* season of 2011-2012. The following map shows the specific location of experimental site (Figure 1). The experimental site was located at $23^0 77$ N latitude and $90^0 3$ E longitudes with an elevation of 1.0 meter from sea level.

3.2 Climate

The annual precipitation of the site is 2026mm and potential evapotranspiration is 1284 mm. The average maximum temperature is 30.32 ^{0}C and average minimum temperature is 21.20^{0}C. The average mean temperature is 26.10 ^{0}C. The experiment was done during the *Rabi* season. Temperature during the cropping period was ranged between 13.20 ^{0}C to 30.2 ^{0}C. The humidity varies from 73.52 % to 81.2 5%. The day length was reduced to 10.5 – 11.0 hours only and there was a very little rainfall from the beginning of the experiment to harvesting (BMD,2012).

3.3 Description of soil

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

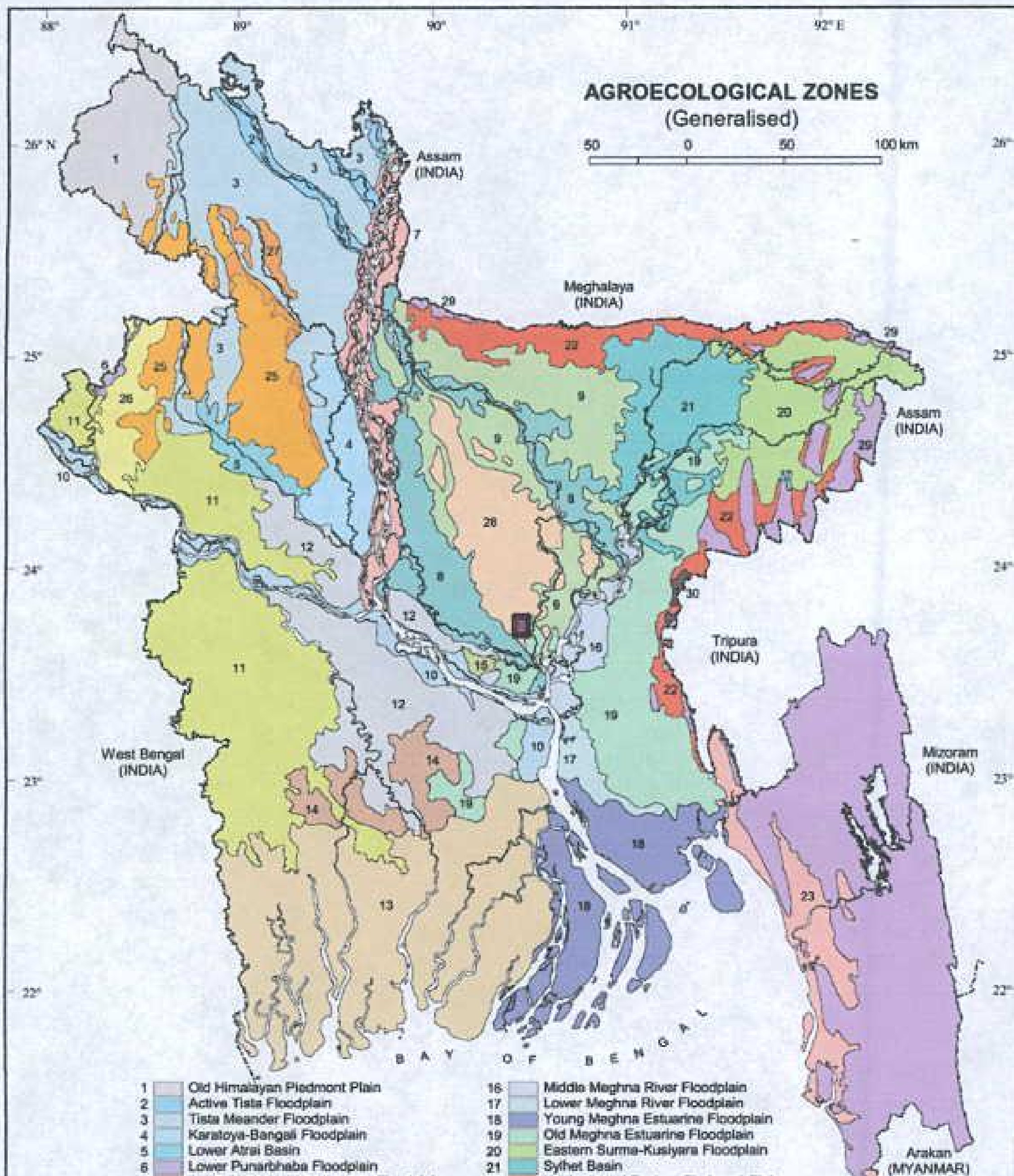

Fig.1. Map showing the experimental site under study

Table 3.1 Morphological characteristics of soil of experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Farm, Dhaka
AEZ No. and name	AEZ-28, Madhupur Tract
General soil type	Deep Red Brown Terrace Soil
Soil series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land type	High land

Table 3.2 Initial characteristics of the soil of the experimental field

Parameters/Properties		Value
1. Particle-size analysis of soil	Sand (%)	30.55
	Silt (%)	37.29
	Clay (%)	32.16
2. Textural Class		Clay loam
3. pH		6.6
4. Total N (%)		0.079
5. Organic matter (%)		0.84
6. Available phosphorous (mg kg^{-1})		15
7. Available potassium (cmol/ kg)		0.35
8. Available sulphur (mg kg^{-1})		12
9. Available zinc (mg kg^{-1})		1.41

3.4 Description of the soybean variety

BARI Soybean-5, a high yielding variety of soybean was used as the test crop in this experiment. This variety was released by Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur in 2002. Life cycle of this variety ranges from 95 to115 days. The variety is resistant to yellow mosaic virus.

3.5 Preparation of the field

The plot selected for the experiment was opened by power tiller driven rotovator on the 15th December 2011; afterwards the land was ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed, and the large clods were broken into smaller pieces to obtain a desirable tilth of soil for sowing of seeds. Finally, the land was leveled and the experimental plot was partitioned into the unit plots in accordance with the experimental design mentioned in the following section (3.6).

3.6 Layout of the experiment

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

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

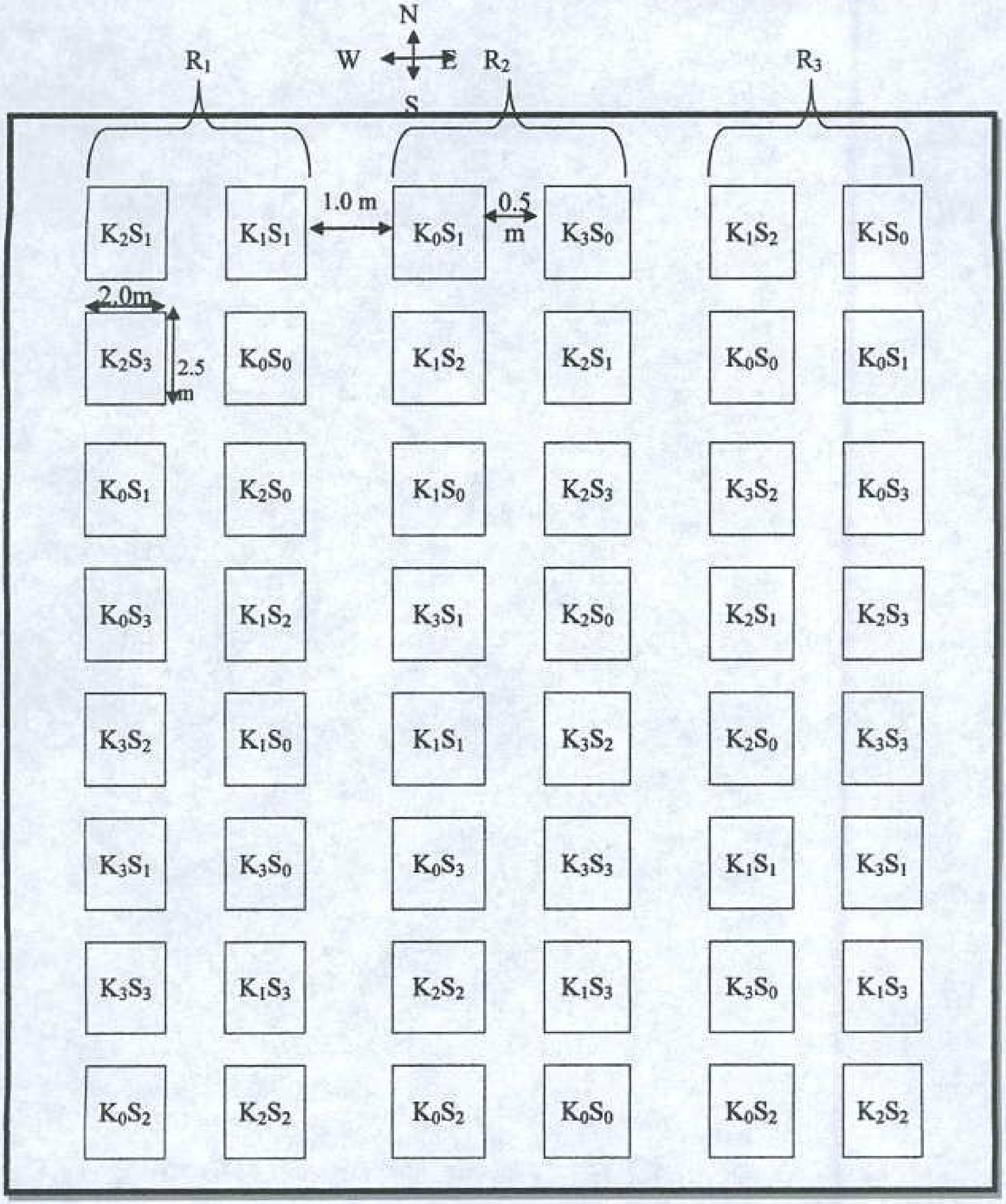

Fig.2. Layout of the experimental field

3.7 Treatments

Fertilizer treatments consisted of 4 levels of K (0, 20, 40 and 60 kg K ha^{-1} designated as K_0, K_1, K_2 and K_3, respectively) and 4 levels of S (0, 10, 20 and 30 kg S ha^{-1} designated as S_0, S_1, S_2 and S_3, respectively).There were 16 treatment combinations. The rates of K and S and their treatment combinations are shown as below:

A. Rates of Potassium (4):

1. $K_0 = 0$ kg K ha^{-1}
2. $K_1 = 20$ kg K ha^{-1}
3. $K_2 = 40$ kg K ha^{-1}
4. $K_3 = 60$ kg K ha^{-1}

B. Rates of sulphur (4):

1. $S_0 = 0$ kg S ha^{-1}
2. $S_1 = 10$ kg S ha^{-1}
3. $S_2 = 20$ kg S ha^{-1}
4. $S_3 = 30$ kg S ha^{-1}

Treatment combinations

1. K_0S_0 =Control (without K and S)
2. K_0S_1 = (0 kg K ha^{-1} + 10 kg S ha^{-1})
3. K_0S_2 = (0 kg K ha^{-1} + 20 kg S ha^{-1})
4. K_0S_3 = (0 kg K ha^{-1} + 30 kg S ha^{-1})
5. K_1S_0 = (20 kg K ha^{-1} + 0 kg S ha^{-1})
6. K_1S_1 = (20 kg K ha^{-1} +10 kg S ha^{-1})
7. K_1S_2 = (20 kg K ha^{-1} + 20 kg S ha^{-1})
8. K_1S_3 = (20 kg K ha^{-1} + 30 kg S ha^{-1})
9. K_2S_0 = (40 kg K ha^{-1} + 0 kg S ha^{-1})
10. K_2S_1 = (40 kg K ha^{-1} + 10 kg S ha^{-1})
11. K_2S_2 = (40 kg K ha^{-1} + 20 kg S ha^{-1})
12. K_2S_3 = (40 kg K ha^{-1} + 30 kg S ha^{-1})
13. K_3S_0 = (60 kg K ha^{-1} + 0 kg S ha^{-1})
14. K_3S_1 = (60 kg K ha^{-1} + 10 kg S ha^{-1})
15. K_3S_2 = (60 kg K ha^{-1} + 20 kg S ha^{-1})
16. K_3S_3 = (60 kg K ha^{-1} + 30 kg S ha^{-1})

3.8 Application of fertilizers

Recommended doses of N, P, Zn and B (30 kg N from urea, 30 kg P from TSP, 2 kg Zn from ZnO and 1 kg B $ha^{-1}$from Boric acid, respectively) were applied.

The whole amounts of TSP, ZnO, Boric acid and half of the urea fertilizer were applied as basal dose during final land preparation. The remaining half of urea was top dressed after 22 days of germination. The required amounts of K (from MP) and S (from gypsum) were applied at a time as per treatment combination after field lay out of the experiment and were mixed properly through hand spading.

3.9 Seed sowing

Soybean seeds were sown on the 24th December 2011 in lines following the recommended line to line distance of 30 cm and plant to plant distance of 5 cm.

3.10 Weeding and thinning

Weeds of different types were controlled manually and removed from the field. The weeding and thinning were done after 20 days of sowing, on January 12, 2012. Care was taken to maintain constant plant population per plot.

3.11 Irrigation

Irrigation was given at three times. The first irrigation was given in the field on January 03, 2012 at ten days after sowing (DAS) through irrigation channel. Second irrigation was given in the field on February 01, 2012 at 40 days after sowing (DAS) before flowering. The third irrigation was given at the stage of pod formation (70 DAS) on March 03, 2012.

3.12 Pest Management

The crop was infested with cutworm at the seedling stage and application of Dursban-25EC @ 2.5ml/liter was applied twice on January 10 and 20, 2012. Special care was taken to protect the crop from birds especially after sowing and germination stages.

3.13 Harvesting

The crop was harvested at maturity on 12th April 2012. The harvested crop of each individual plot was bundled separately. Grain and straw yields were recorded plot wise and the yields were expressed in t ha^{-1}.

3.14 Collection of samples

3.14.1 Soil Sample

The initial soil sample was collected randomly from different spots of the field selected for the experiment at 0-15 cm depth before the land preparation and mixed thoroughly to make a composite sample for analysis. Post harvest soil samples were collected from each plot at 0-15 cm depth on 13^{th} April 2012. The samples were air - dried, ground and sieved through a 2 mm (10 mesh) sieve and kept for analysis at Bangladesh Agricultural Research Institute (BARI), Joydebpur,Gazipur.

3.14.2 Plant sample

Plant samples were collected from every individual plot for laboratory analysis at the harvesting stage of the crop. Ten plants were randomly collected from each plot by cutting above the ground level. The plant samples were washed first with tape water and then with distilled water several times. The plant samples were dried in the electric oven at 70^0 C for 72 hours. After that the samples were ground in an electric grinding machine and stored for chemical analysis. The plant samples were collected by avoiding the border area of the plots.

3.15 Collection of data

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

1) Plant height (cm)
2) Number of leaves plant^{-1}
3) Number of primary branches plant^{-1}
4) Number of pods plant^{-1}
5) Number of seeds plant^{-1}
6) Thousand seed weight (g)
7) Grain yield (t ha^{-1})
8) Straw yield (t ha^{-1})
9) Protein content in seed (%)
10) Oil content in seed (%)
11) N, P, K, S and Zn contents in plant sample
12) N, P, K, S and Zn contents in post harvest soil.

3.15.1 Plant height

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

3.15.2 Number of leaves

Numbers of leaves plant^{-1} were counted at the maximum vegetative stage.The Ten plants were selected randomly from each plot and averaged.

3.15.3 Number of primary branches

Numbers of primary branches plant^{-1} were counted at the maximum vegetative stage.Ten plants were selected randomly from each plot and averaged.

3.15.4 Number of pods

Pods plant^{-1} were counted at the ripening stage and ten plants were selected from each plot and averaged.

3.15.5 Number of seeds

It was done after harvesting. At first, number of seeds pod^{-1} were counted and averaged. Then it was multiplied with number of pods plant^{-1}. Ten plants were selected and averaged.

3.15.6 Thousand seed weight

Thousand seed of soybean were counted randomly and then weighed (g) plot wise.

3.15.7 Grain yield

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

3.15.8 Straw yield

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

3.16 Chemical analysis of the plant, soil and seed samples

3.16.1 Plant sample analysis

The plant samples collected at different growth stages of the crop were digested with conc. HNO_3 and $HClO_4$ mixture for the determination of P, K and S and Zn.

3.16.1. a) Phosphorous

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

3.16.1. b) Potassium

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

3.16.1. c) Sulphur

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

3.16.1. d) Nitrogen

Plant samples were digested with conc. H_2SO_4, 30% H_2O_2 and a catalyst mixture (K_2SO_4 : $CuSO_4.5H_2O$: Selenium powder in the ratio 100 : 10 : 1, respectively) for the determination of total nitrogen by Micro-Kjeldal method. Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate absorbed in H_3BO_3 with 0.01N H_2SO_4 (Jackson, 1973).

3.16.1. e) Zinc

Zn content in the digest of the plant samples were determined by Atomic Absorbance Spectrophotometer.

3.16.2 Soil sample analysis

3.16.2. a) Organic carbon

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

3.16.2. b) Organic matter

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

3.16.2. c) Total nitrogen

Total nitrogen of soil samples were estimated by Micro-Kjeldahl method where soils were digested with conc. H_2SO_4, 30% H_2O_2 and catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Selenium powder in the ratio 100 :10 :1, respectively). Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate absorbed in H_3BO_3 with 0.01N H_2SO_4 (Jackson, 1973).

3.16.2. d) Available Phosphorous

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

3.16.2. e) Available Potassium

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

3.16.2. f) Available Sulphur

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

3.16.2. g) Available Zinc

Zinc in the extract was determined by the DTPA extracting solution method as described by Lindsay and Norwell (1978) using an Atomic Absorbing Spectrophotometer.

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

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

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

3.19 Statistical analysis

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

Chapter 4
Results and Discussion

Chapter 4

RESULTS AND DISCUSSION

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

4.1 Plant height

4.1.1 Effect of potassium on the plant height of soybean

The effects of potassium on the plant height of soybean are presented in Table 4.1. Significant variation was observed on the plant height of soybean when the field was fertilized with different doses of potassium. Among the different doses of potassium, K_2 (40 kg K ha^{-1}) showed the highest plant height (69.14 cm) which was statistically similar with K_3 treatment. On the other hand, the lowest plant height (59.53 cm) was observed in the K_0 *ie.*control treatment where no potassium was applied. Plant height increased with increasing levels of potassium up to certain level. The increased plant height may be due to favorable effects of potassium on the vegetative growth of soybean plant. Hungria and Franchini (2000) also found similar results with the application of 90 kg K_2O/ha.

Table 4.1 Effects of K on the plant height and yield components of soybean

Treatments	Plant height (cm)	Number of primary branches $plant^{-1}$	Number of leaves $plant^{-1}$	Number of pods $plant^{-1}$	Number of seeds $plant^{-1}$
K_0	59.53 c	3.09 c	16.93 d	34.17 d	99.50 d
K_1	63.66 b	3.60b	18.35 c	42.60 c	125.8 c
K_2	69.14 a	4.32 a	21.53 a	49.51 a	146.5 a
K_3	68.57 a	4.15 a	20.97 b	47.67 b	141.5 b
$LSD_{0.05}$	0.953	0.273	0.310	0.467	1.105
CV (%)	7.89	7.22	6.95	5.39	8.12

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$,K_3=60 $kgha^{-1}$

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

4.1.2 Effect of sulphur on the plant height of soybean

Soybean plants showed significant variation in respect of plant height when sulphur fertilizer in different doses was applied (Table 4.2). Among the different fertilizer doses, S_2 (20 kg S ha^{-1}) showed the highest plant height (70.73cm). On the contrary, the lowest plant height (60.08 cm) was observed in the treatment (S_o) where no sulphur fertilizer was applied. Plant height increased with increasing levels of sulphur up to certain level. The increased plant height may be due to favourable effects of sulphur on the vegetative growth of soybean plant. Sriramchandrasekharan *et al.* (2004) reported that the highest plant height was obtained with the application of 30 kg S/ha in the presence of *Bradyrhizobium* inoculation. Mohanti *et al.* (2004) observed that the highest plant height was obtained with the application of 30 kg S/ha. Saran and Giri (1990) found that the highest plant height was obtained with the application of 60 kg S ha^{-1}.

Table 4.2 Effects of S on the plant height and yield components of soybean

Treatments	Plant height (cm)	Number of primary branches $plant^{-1}$	Number of leaves $plant^{-1}$	Number of pods $plant^{-1}$	Number of seeds $plant^{-1}$
S_0	60.08 d	3.34c	18.07 d	36.40 d	107.21 d
S_1	62.99 c	3.74b	19.98 c	43.09 c	127.21 c
S_2	70.73 a	4.17a	22.86 a	48.40a	143.71 a
S_3	67.09 b	3.90ab	20.93 b	46.09 b	136.30 b
$LSD_{0.05}$	0.951	0.270	0.306	0.465	1.107
CV (%)	7.89	7.22	6.95	5.39	8.12

S_0=0 $kgha^{-1}$, S_1=10 $kgha^{-1}$, S_2=20 $kgha^{-1}$, S_3=30 $kgha^{-1}$

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

4.1.3 Interaction effect of potassium and sulphur on the plant height of soybean

Combined application of different doses of potassium and sulphur fertilizers had significant effect on the plant height of soybean (Fig.3). The lowest plant height (52.73cm) was observed in the control treatment (No potassium and No sulphur). On the other hand, the highest plant height (74.40 cm) was recorded with K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment (Appendix-VI). The highest plant height may be due to the positive effects of potassium and sulphur on the vegetative growth and accumulation of materials.

4.2 Number of primary branches

4.2.1 Effect of potassium on the number of primary branches of soybean

Significant variation was observed in the number of primary branches plant^{-1} of soybean when different doses of potassium were applied (Table 4.1). The highest number of primary branches plant^{-1} (4.32) was recorded in K_2 (40 kg K ha^{-1}) which was statistically similar with the K_3 (60 kg K ha^{-1}) treatment. The lowest number of primary branches plant^{-1} (3.09) was recorded in the K_0 treatment where no potassium was applied. The increased number of primary branches/plant may be due to favorable effects of potassium on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean plant.

4.2.2 Effect of sulphur on the number of primary branches of soybean

Different doses of sulphur fertilizer showed significant variations in respect of number of primary branches plant^{-1} (Table 4.2). Among the different doses of sulphur, S_2 (20 kg S ha^{-1}) showed the highest number of primary branches plant^{-1} (4.17) which was statistically similar with the S_3 (30 kg S ha^{-1}) treatment. On the contrary, the lowest number of primary branches plant^{-1} (3.34) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased number of primary branches/plant may be due to positive effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean plant. Mohanti *et al*. (2004) found similar results with the application of 30 kg S/ha.

4.2.3 Interaction effect of potassium and sulphur on the number of primary branches of soybean

The combined effect of different doses of K and S fertilizer on the number of primary branches plant^{-1} of soybean was significant (Fig.4). The highest number of primary branches plant^{-1} (4.87) was recorded with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) treatment (Appendix-VI). On the other hand, the lowest number of primary branches plant^{-1} (2.94) was recorded in the K_0S_0 treatment (control treatment). The highest number of primary branches plant^{-1} may be due to the fact that, the combined effect of both potassium and sulphur played positive effect on the growth and development of soybean plant.

4.3 Number of leaves

4.3.1 Effect of potassium on the number of leaves of soybean

Significant variation was observed in the number of leaves plant^{-1} of soybean when different doses of potassium were applied (Table 4.1). The highest number of leaves plant^{-1} (21.53) was recorded in K_2 (40 kg K ha^{-1}) treatment. The lowest number of leaves plant^{-1} (16.93) was recorded in the K_0 treatment where no potassium was applied. The increased number of leaves plant^{-1} may be due to favorable effects of potassium on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean plant.

4.3.2 Effect of sulphur on the number of leaves of soybean

Different doses of sulphur fertilizer showed significant variations in respect of number of leaves plant^{-1} (Table 4.2). Among the different doses of fertilizers, S_2 (20 kg S ha^{-1}) showed the highest number of leaves plant^{-1} (22.86). On the contrary, the lowest number of leaves plant^{-1} (18.07) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased number of leaves plant^{-1} may be due to favorable effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean plant. Saran and Giri (1990) also found similar results with the application of 60 kg S ha^{-1}.

4.3.3 Interaction effect of potassium and sulphur on the number of leaves of soybean

The combined effect of different doses of K and S fertilizers on the number of leaves plant^{-1} of soybean was significant (Fig.5). The highest number of leaves plant^{-1} (25.49) was recorded with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) treatment (Appendix-VI). On the other hand, the lowest number of leaves plant^{-1} (16.81) was recorded in the K_0S_0 treatment (control treatment). The highest number of leaves plant^{-1} may be due to the fact that, the combined effect of both potassium and sulphur played positive effect on the growth and development of soybean plant.

4.4 Number of pods

4.4.1 Effect of potassium on the number of pods of soybean

Significant variation was observed in the number of pods plant^{-1} of soybean when different doses of potassium were applied (Table 4.1). The highest number of pods plant^{-1} (49.51) was recorded in K_2 (40 kg K ha^{-1}) treatment. The lowest number of pods plant^{-1} (34.17) was recorded in the K_0 treatment where no potassium was applied. The increased number of pods plant^{-1} may be due to favorable effects of potassium on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean pod. The application of 60 kg K_2O/ha at budding stage resulted to an increase in the number of pods per plant (Hungria and Franchini, 2000).

4.4.2 Effect of sulphur on the number of pods of soybean

Different doses of sulphur fertilizer showed significant variations in respect of number of pods plant^{-1} (Table 4.2). Among the different doses of fertilizers, S_2 (20 kg S ha^{-1}) showed the highest number of pods plant^{-1} (48.40). On the contrary, the lowest number of pods plant^{-1} (36.40) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased number of pods plant^{-1} may be due to favorable effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean pod. Sriramchandrasekharan *et al.* (2004) found similar results with the application of 30 kg S/ha in the presence of *Bradyrhizobium* inoculation. Arunageeta and Senthilkumar, (2006) observed that the highest number of pods plant^{-1} was obtained with the application of 30 kg S/ha.

4.4.3 Interaction effect of potassium and sulphur on the of number of pods of soybean

The combined effect of different doses of K and S fertilizers on the number of pods plant^{-1} of soybean was significant (Fig.6). The highest number of pods plant^{-1} (53.80) was recorded with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) and K_2S_3 (40 kg K ha^{-1} + 30 kg S ha^{-}1) treatment (Appendix-VI). On the other hand, the lowest number of pods plant^{-1} (28.18) was recorded in the K_0S_0 treatment (control treatment). The highest number of pods plant^{-1} may be due to the fact that, the combined effect of both potassium and sulphur had positive effect on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean pod.

4.5 Number of seeds

4.5.1 Effect of potassium on the number of seeds of soybean

Significant variation was observed in the number of seeds plant^{-1} of soybean when different doses of potassium were applied (Table 4.1). The highest number of seeds plant^{-1} (146.5) was recorded in K_2 (40 kg K ha^{-1}) treatment. The lowest number of seeds plant^{-1} (99.50) was recorded in the K_0 treatment where no potassium was applied. The number of seeds plant^{-1} increased with increasing levels of potassium up to certain level. The increased number of seeds plant^{-1} may be due to the favorable effects of potassium on the vegetative growth and accumulation of materials that helped in obtaining the highest number of seeds plant^{-1} of soybean. Hungria and Franchini (2000) also found similar results with the application of 60 kg K_2O/ha.

4.5.2 Effect of sulphur on the number of seeds of soybean

Different doses of sulphur fertilizer showed significant variations in respect of number of seeds plant^{-1} (Table 4.2). Among the different doses of fertilizers, S_2 (20 kg S ha^{-1}) showed the highest number of seeds plant^{-1} (143.71). On the contrary, the lowest number of seeds plant^{-1} (107.21) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased number of seeds plant^{-1} may be due to the favorable effects of sulphur on the vegetative growth and accumulation of materials that helped in obtaining the highest number of seeds plant^{-1} of soybean. Saran and Giri (1990) also found similar results with the application of 60 kg S ha^{-1}

4.5.3 Interaction effect of potassium and sulphur on the of number of seeds of soybean

The combined effect of different doses of K and S fertilizers on the number of seeds plant^{-1} of soybean was significant (Fig.7). The highest number of seeds plant^{-1} (159.6) was recorded with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) treatment (Appendix-VI). On the other hand, the lowest number of seeds plant^{-1} (83.45) was recorded in the K_0S_0 treatment (control treatment). Optimum fertilizer doses increase the vegetative growth and development of soybean that lead to the formation of the highest number of seeds plant^{-1}.

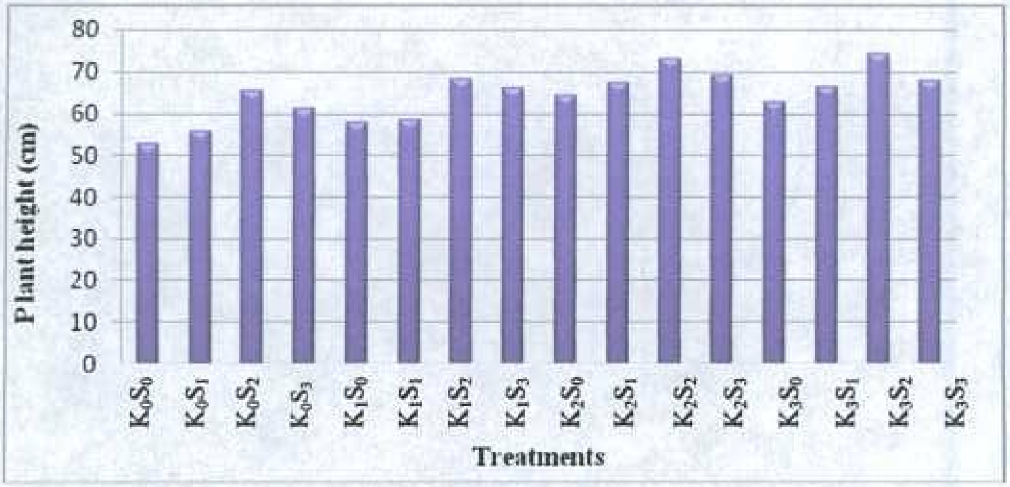

Fig.3. Combined effect of K and S on the plant height of soybean

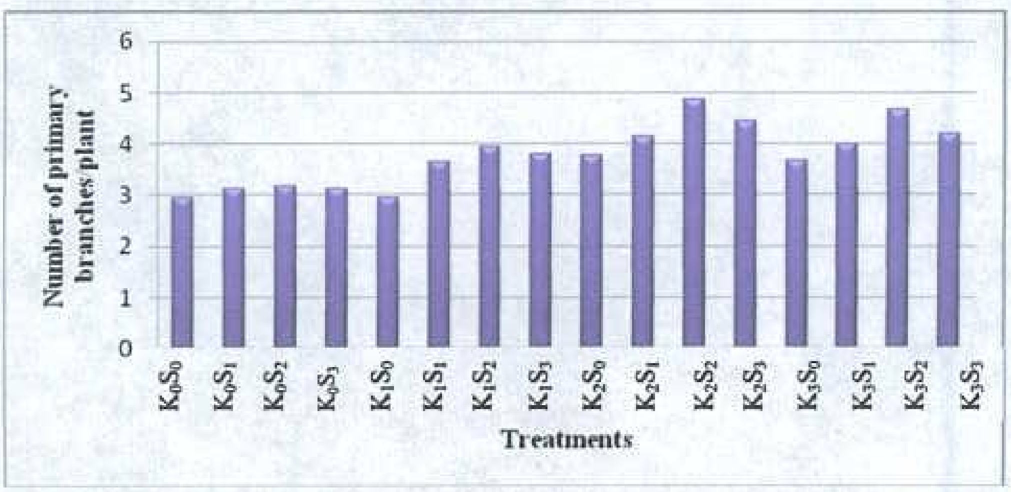

Fig.4. Combined effect of K and S on the number of primary branches/plant of soybean

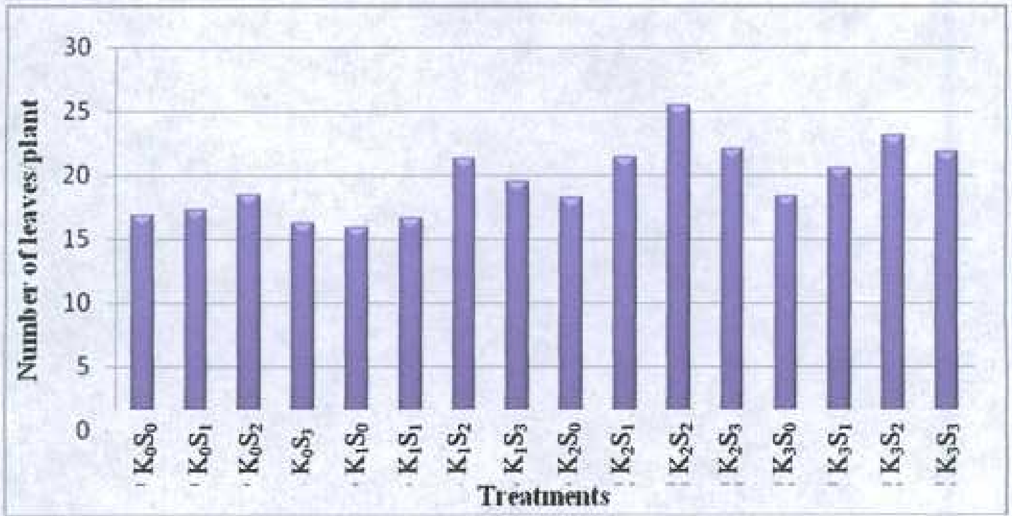

Fig.5. Combined effect of K and S on the number of leaves/plant of soybean

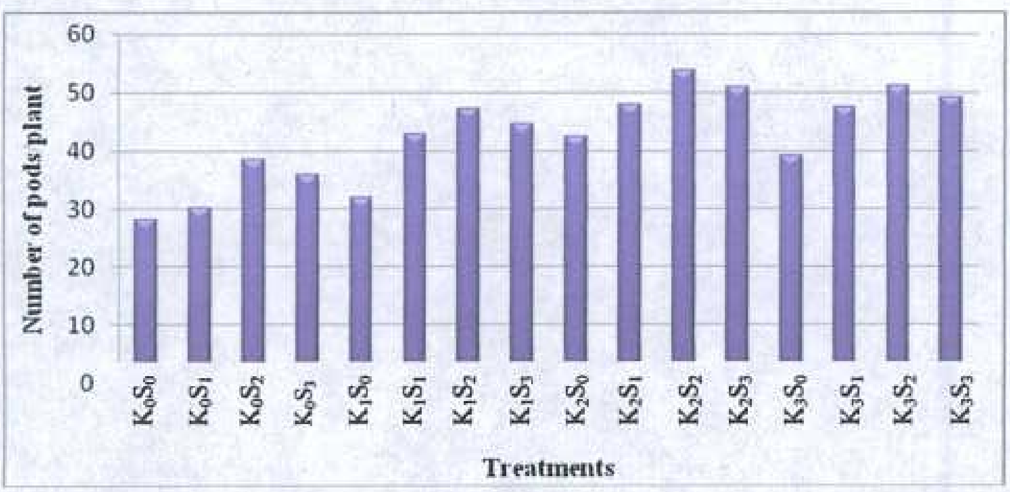

Fig.6. Combined effect of K and S on the number of pods/plant of soybean

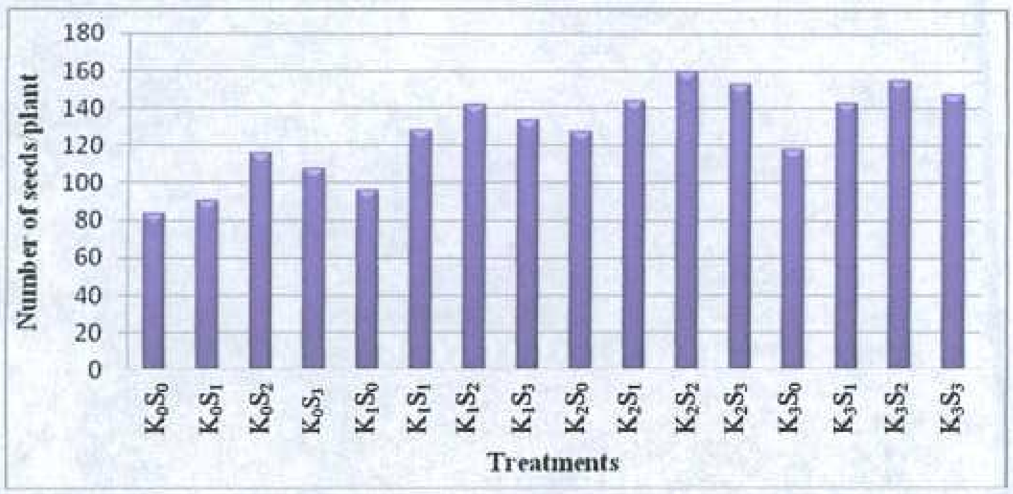

Fig.7. Combined effect of K and S on the number of seeds/plant of soybean

4.6 Weight of 1000 seed

4.6.1 Effect of potassium on the weight of 1000 seed of soybean

Significant variation was observed on the weight (g) of 1000 seed of soybean when different doses of potassium were applied (Table 4.3). The highest weight of 1000 seed (123.78 g) was recorded in K_2 (40 kg K ha^{-1}) treatment. The lowest weight of 1000 seed (119.05 g) was recorded in the K_0 treatment where no potassium was applied. The increased grain weight may be due to the favourable effects of potassium on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean grain. Habibzadeh *et al.* (2004) revealed that the highest 1000-seed weight (90.6 g) was obtained with 225 kg K/ha.

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

Different doses of sulphur fertilizer showed significant variations in respect of the weight (g) of 1000 seed (Table 4.4). Among the different doses of S fertilizer, S_2 (20 kg S ha^{-1}) showed the highest weight of 1000 seed (122.86 g). On the contrary, the lowest weight of 1000 seed (119.40 g) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased grain weight may be due to the positive effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean grain. Saran and Giri (1990) also found similar results with the application of 60 kg S ha^{-1}.

Table 4.3 Effect of K on the yield parameters of soybean

Treatments	1000 seed weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
K_0	119.05 c	1.57 d	1.47 c
K_1	121.79 b	1.84 c	1.80 b
K_2	123.78 a	2.20 a	1.90 a
K_3	121.60 b	2.01 b	1.92 a
$LSD_{0.05}$	0.3596	0.102	0.087
CV (%)	9.58	4.81	5.18

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$,K_3=60 $kgha^{-1}$

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

4.6.3 Interaction effect of potassium and sulphur on the weight of 1000 seed of soybean

The combined effect of different doses of K and S fertilizers on the weight (g) of 1000 seed of soybean was significant (Table 4.5). The highest weight of 1000 seed (124.90 g) was recorded with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}). On the other hand, the lowest weight of 1000 seed (115.20 g) was recorded in the K_0S_0 treatment (control treatment). The weight of 1000 seed increased with increasing level of potassium and sulphur up to certain level due to the favourable effects of fertilizer on the yield attributes. Singh and Singh (1995) also found similar result with the application of 50 kg K_2O and 40 kg S ha^{-1}.

4.7 Grain yield of soybean

4.7.1 Effect of potassium on the grain yield of soybean

Significant variation was observed on the grain yield (t ha^{-1}) of soybean when different doses of potassium were applied (Table 4.3). The highest grain yield of soybean (2.20 t ha^{-1}) was recorded in K_2 (40 kg K ha^{-1}) treatment. The lowest grain yield (1.57 t ha^{-1}) was recorded in the K_0 treatment where no potassium was applied. The increased grain yield may be due to the positive effects of potassium on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean grain. Grewal *et al.* (1994) observed that the soybean grain yield increased with the application of 50 kg K_2O/ha. Annadurai *et al.* (1994) observed that the application of 40 kg K_2O/ha increased the soybean seed yield.

4.7.2 Effect of sulphur on the grain yield of soybean

Different doses of sulphur fertilizer showed significant variations in respect of grain yield (t ha^{-1}) of soybean (Table 4.4). Among the different doses of S fertilizer, S_2 (20 kg S ha^{-1}) showed the highest grain yield of soybean (2.32 t ha^{-1}) which was statistically similar with S_3 (30 kg S ha^{-1}) treatment. On the contrary, the lowest weight grain yield of soybean (1.61 t ha^{-1}) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased grain yield may be due to the favourable effects of sulphur on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean grain. Sriramchandrasekharan *et al.* (2004) found similar results with the application of 30 kg S/ha in the presence of *Bradyrhizobium* inoculation. Sangale and Sonar (2004) observed that application of S at 20 kg/ha gave highest seed yield. Mohanti *et al.* (2004) found similar results with the application of 30 kg S/ha. Tomar *et al.* (2000) reported that the highest seed yield (2257 kg/ha) was recorded with the application of 50 kg S/ha regardless of sources.

Table 4.4 Effect of S on the yield parameters of soybean

Treatments	1000 seed weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
S_0	119.40 d	1.61 c	1.52 d
S_1	121.67 c	1.81 b	1.75 c
S_2	122.86 a	2.32 a	1.95 a
S_3	122.30 b	2.24 a	1.87 b
$LSD_{0.05}$	0.363	0.099	0.083
CV (%)	9.58	4.81	5.18

S_0=0 $kgha^{-1}$, S_1=10 $kgha^{-1}$, S_2=20 $kgha^{-1}$, S_3=30 $kgha^{-1}$

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

4.7.3 Interaction effect of potassium and sulphur fertilizers on the grain yield of soybean

The combined effect of different doses of K and S fertilizers on the grain yield (t ha^{-1}) of soybean was significant (Table 4.5 and Fig.8). The highest grain yield of soybean (2.40 t ha^{-1}) was recorded with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}). On the other hand, the lowest grain yield of soybean (1.38 t ha^{-1}) was recorded in the K_0S_0 treatment (control treatment). Grain yield increased with increasing level of potassium and sulphur up to certain level due to the positive effect of fertilizers on the yield attributes. Singh and Singh (1995) also found similar result with the application of 50 kg K_2O and 40 kg S ha^{-1}.

4.8 Straw yield of soybean

4.8.1 Effect of potassium on the straw yield of soybean

Significant variation was observed on the straw yield (t ha^{-1}) of soybean when different doses of potassium were applied (Table 4.3). The highest straw yield of soybean (1.92 t ha^{-1}) was recorded in K_3 (60 kg K ha^{-1}) which was statistically similar with K_2 (40 kg K ha^{-1}) treatment. The lowest straw yield (1.47 t ha^{-1}) was recorded in the K_0 treatment where no potassium was applied.

4.8.2 Effect of sulphur on the straw yield of soybean

Different doses of sulphur fertilizer showed significant variations in respect of straw yield (t ha^{-1}) of soybean (Table 4.4). Among the different doses of S fertilizer, S_2 (20 kg S ha^{-1}) showed the highest straw yield of soybean (1.95 t ha^{-1}). On the contrary, the lowest straw yield of soybean (1.52 t ha^{-1}) was recorded in the S_0 treatment where no sulphur fertilizer was applied.

Table 4.5 Interaction effect of K and S on the yield parameters of soybean

Treatments	1000 seed weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
K_0S_0	115.20 k	1.38 g	0.94 h
K_0S_1	119.61 i	1.45 g	1.43 g
K_0S_2	121.25 gh	1.78 ef	1.87 b-d
K_0S_3	120.13 i	1.72 f	1.62 ef
K_1S_0	118.53 j	1.45 g	1.53 fg
K_1S_1	122.31 d-f	1.95 cd	1.81 d
K_1S_2	123.50 bc	2.00 c	1.85 cd
K_1S_3	122.81 c-e	1.96 cd	2.00 ab
K_2S_0	123.00 cd	1.87 c-e	1.85 cd
K_2S_1	123.12 c	1.98 c	1.77 d
K_2S_2	124.90 a	2.40 a	2.00 ab
K_2S_3	124.10 b	2.15 b	1.97 a-c
K_3S_0	120.86 h	1.77 ef	1.74 de
K_3S_1	121.62 fg	1.85 d-f	1.97 a-c
K_3S_2	121.79 fg	2.18 b	2.08 a
K_3S_3	122.15 ef	2.13 b	1.87 b-d
$LSD_{0.05}$	0.719	0.118	0.129
CV (%)	9.58	4.81	5.18

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$,K_3=60 $kgha^{-1}$

S_0=0 $kgha^{-1}$, S_1=10 $kgha^{-1}$, S_2=20 $kgha^{-1}$, S_3=30 $kgha^{-1}$

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

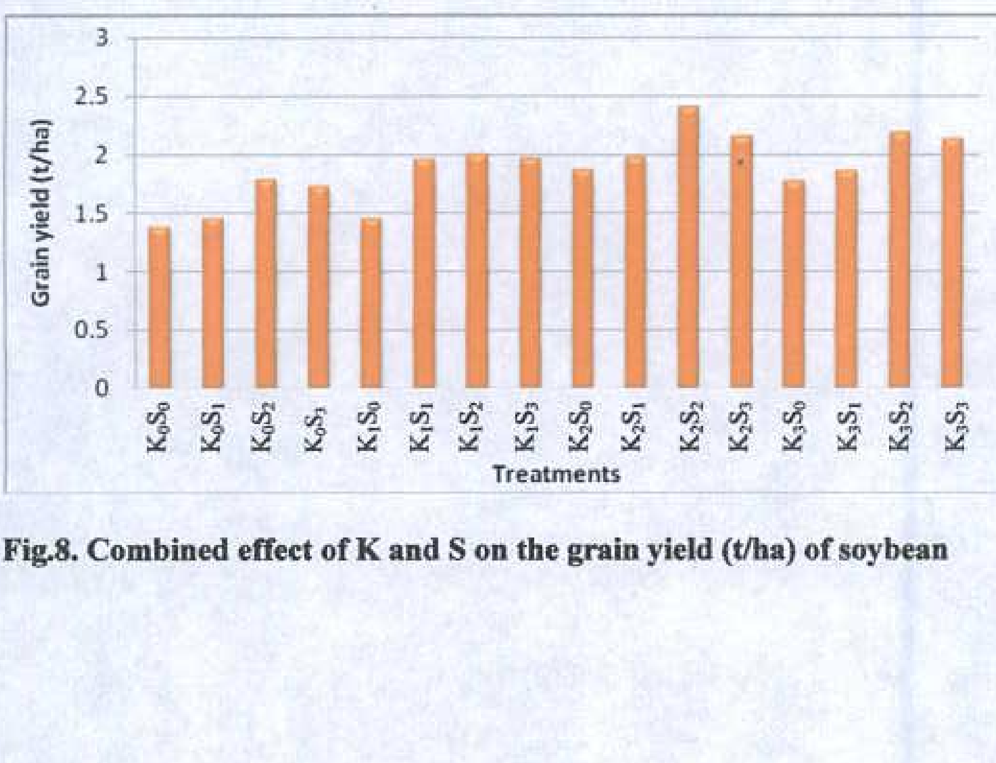

Fig.8. Combined effect of K and S on the grain yield (t/ha) of soybean

4.8.3 Interaction effect of potassium and sulphur fertilizers on the straw yield of soybean

The combined effect of different doses of K and S fertilizers on the straw yield of soybean was significant (Table 4.5). The highest straw yield of soybean (2.08 t ha^{-1}) was recorded with the treatment combination of K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically identical with the treatment combination of K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}), K_1S_3 (20 kg K ha^{-1} + 30 kg S ha^{-1}), K_2S_3(40 kg K ha^{-1}+ 30 kg S ha^{-1}) and K_3S_1 (60 kg K ha^{-1} +10 kg S ha^{-1}). On the other hand, the lowest straw yield of soybean (0.94 t ha^{-1}) was recorded in the K_0S_0 treatment (control treatment).

4.9 Nitrogen content in soybean plant

4.9.1 Effect of K on nitrogen content in soybean plant

Application of K showed significant variation on the nitrogen concentration (%) in soybean plant (Table 4.6). The highest nitrogen concentration in soybean plant (1.35%) was recorded in K_3 (60 kg K ha^{-1}) treatment. On the other hand, the lowest nitrogen concentration in soybean plant (0.97%) was recorded in the K_0 treatment where no K was applied.

4.9.2 Effect of S on nitrogen content in soybean plant

The effect of different doses of sulphur showed statistically significant difference on the nitrogen concentration (%) in soybean plant (Table 4.7). The highest nitrogen concentration among the treatments of sulphur (1.31%) was observed in S_2 (20 kg S ha^{-1}) which was statistically similar with S_3 (30 kg S ha^{-1}) treatment. On the other hand, the lowest nitrogen concentration in soybean plant (1.08%) was observed in the S_0 (control condition) treatment.

4.9.3 Interaction effect of K and S on nitrogen content in soybean plant

Significant effect of combined application of different doses of K and S fertilizers on the nitrogen concentration was observed in the soybean plant (Table 4.8). The highest concentration (1.51%) of nitrogen in the soybean plant was recorded with K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with K_3S_3 (60 kg K ha^{-1} + 30 kg S ha^{-1}), K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) and K_2S_3 (40 kg K ha^{-1} + 30 kg S ha^{-1}) treatment combinations. On the other hand, the lowest nitrogen concentration in soybean plant (0.86%) was observed in the K_0S_0 treatment (Jackson,1973).

Table 4.6 Effect of K on the N, P, K, S and Zn contents in soybean plant

Treatments	N (%)	P (%)	K (%)	S (%)	Zn (ppm)
K_0	0.97d	0.171	0.536 c	0.346 c	48.72 d
K_1	1.15c	0.259	0.644 b	0.414 b	56.10 a
K_2	1.23b	0.274	0.696 a	0.471 a	54.37 b
K_3	1.35 a	0.271	0.720 a	0.484a	53.37c
$LSD_{0.05}$	0.037	NS	0.0457	0.0527	0.869
CV (%)	4.61	4.28	3.19	6.10	4.99

Ko=0 kgha^{-1}, K_1=20 kgha^{-1}, K_2=40 kgha^{-1},K_3=60 kgha^{-1}

NS=Not significant

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

4.10 Phosphorus content in soybean plant

4.10.1 Effect of K on phosphorus content in soybean plant

A statistically insignificant variation was observed on phosphorus concentration (%) in soybean plant with different doses of potassium (Table 4.6). However, the highest phosphorus concentration (0.274%) among the different doses of potassium was recorded in K_2 (40 kg K ha^{-1}). On the other hand, the lowest phosphorus concentration in soybean plant (0.171%) was recorded in the K_0 treatment where no K was applied.

4.10.2 Effect of S on phosphorus content in soybean plant

A statistically insignificant variation was observed on phosphorus concentration (%) in soybean plant with different doses of sulphur (Table 4.7). However, the highest phosphorus concentration (0.274%) among the different doses of sulphur was recorded in S_2 (20 kg S ha^{-1}). On the other hand, the lowest phosphorus concentration in soybean plant (0.219%) was recorded in the S_0 treatment where no S was applied.

4.10.3 Interaction effect of K and S on phosphorus content in soybean plant

Insignificant effect of combined application of different doses of K and S fertilizers on the phosphorus concentration was observed in the soybean plant (Table 4.8). However, the highest concentration of phosphorus in the soybean plant (0.34%) was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment. On the other hand, the lowest phosphorus concentration in soybean plant (0.15%) was observed in K_0S_0 treatment (Murphy and Riley, 1962).

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

Treatments	N (%)	P (%)	K (%)	S (%)	Zn (ppm)
S_0	1.08 b	0.219	0.611	0.374 b	51.13c
S_1	1.00 c	0.231	0.636	0.396b	50.97c
S_2	1.31a	0.274	0.665	0.461a	56.59a
S_3	1.30 a	0.251	0.684	0.484 a	53.87b
$LSD_{0.05}$	0.046	NS	NS	0.0646	0.8705
CV (%)	4.61	4.28	3.19	6.10	4.99

S_0=0 kgha^{-1}, S_1=10 kgha^{-1}, S_2=20 kgha^{-1}, S_3=30 kgha^{-1}

NS=Not significant

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

4.11 Potassium content in soybean plant

4.11.1 Effect of K on potassium content in soybean plant

Application of K showed significant variation on the potassium concentration (%) in soybean plant (Table 4.6). The highest potassium concentration in soybean plant (0.720%) was recorded in K_3 (60 kg K ha^{-1}) treatment which was statistically similar with K_2 (40 kg K ha^{-1}) treatment. On the other hand, the lowest potassium concentration in soybean plant (0.536%) was recorded in the K_0 treatment where no K was applied. The highest potassium concentration was observed due to the positive effect of potassium on potassium content in soybean plant up to certain limit.

4.11.2 Effect of S on potassium content in soybean plant

A statistically insignificant variation was observed on potassium concentration (%) in soybean plant with different doses of sulphur (Table 4.7). However, the highest potassium concentration (0.684%) among the different doses of sulphur was recorded in S_3 (30 kg S ha^{-1}). On the other hand, the lowest potassium concentration in soybean plant (0.611%) was recorded in the S_0 treatment where no S was applied. The highest potassium concentration was observed due to the positive effect of sulphur on potassium content in soybean plant up to certain limit.

4.11.3 Interaction effect of K and S on potassium content in soybean plant

Significant effect of combined application of different doses of K and S fertilizers on the potassium concentration was observed in the soybean plant (Table 4.8). The highest concentration of potassium in the soybean plant (0.77%) was recorded with the K_3S_3 (60 kg K ha^{-1} + 30 kg S ha^{-1}) which was statistically similar with K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment. On the other hand, the lowest potassium concentration (0.42%) in soybean plant was observed in K_0S_0 treatment. This might be due to the fact that, the combined effect of both potassium and sulphur played positive effect on potassium content in soybean plant up to certain limit.

4.12 Sulphur content in soybean plant

4.12.1 Effect of K on sulphur content in soybean plant

Application of K showed significant variation on the sulphur concentration (%) in soybean plant (Table 4.6). The highest sulphur concentration in soybean plant (0.484%) was recorded in K_3 (60 kg K ha^{-1}) treatment which was statistically similar with K_2 (40 kg K ha^{-1}) treatment. On the other hand, the lowest sulphur concentration in soybean plant (0.346%) was recorded in the K_0 treatment where no K was applied. The highest sulphur concentration was observed due to the positive effect of potassium on sulphur content in soybean plant up to certain limit.

4.12.2 Effect of S on sulphur content in soybean plant

The effect of different doses of sulphur showed statistically significant difference on the sulphur concentration (%) in soybean plant (Table 4.7). The highest sulphur concentration among the treatments of sulphur (0.484%) was observed in S_3 (30 kg S ha^{-1}) which was statistically similar with S_2 (20 kg S ha^{-1}) treatment. On the other hand, the lowest sulphur concentration in soybean plant (0.374%) was observed in the S_0 (control condition) treatment. The highest sulphur concentration was observed due to the positive effect of sulphur on sulphur content in soybean plant up to certain limit.

4.12.3 Interaction effect of K and S on sulphur content in soybean plant

Significant effect of combined application of different doses of K and S fertilizers on the sulphur concentration was observed in the soybean plant (Table 4.8). The highest concentration of sulphur in the soybean plant (0.56%) was recorded with the K_3S_3 (60 kg K ha^{-1} + 30 kg S ha^{-1}) and K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment which were statistically similar with K_2S_3 (40 kg K ha^{-1} + 30 kg S ha^{-1}) treatment combination. On the other hand, the lowest sulphur concentration (0.29%) in soybean plant was observed in K_0S_0 treatment. This might be due to the fact that, the combined effect of both potassium and sulphur played positive effect on sulphur content in soybean plant up to certain limit (Hunt,1980).

Table 4.8 Interaction effects of K and S on the N, P, K, S and Zn contents in soybean plant

Treatments	N (%)	P (%)	K (%)	S (%)	Zn (ppm)
K_0S_0	0.86 e	0.15	0.42 h	0.29i	42.55 i
K_0S_1	0.93 d	0.18	0.48 g	0.31 hi	47.60 h
K_0S_2	0.97 d	0.22	0.61 ef	0.39 fg	53.85 c-e
K_0S_3	1.10 c	0.15	0.65 d-f	0.41 d-f	50.86 fg
K_1S_0	1.15 c	0.21	0.66 c-e	0.35 gh	55.85 b
K_1S_1	0.99 d	0.28	0.65 d-f	0.40 e-g	54.30 b-e
K_1S_2	1.28 b	0.25	0.60 f	0.43 c-f	58.35 a
K_1S_3	1.12 c	0.29	0.66 c-e	0.47 b-d	55.87 b
K_2S_0	0.98 d	0.26	0.68 cd	0.42 d-f	55.01 b-d
K_2S_1	0.95 d	0.21	0.69 b-d	0.41 ef	49.26 gh
K_2S_2	1.51 a	0.34	0.74 ab	0.56 a	59.87a
K_2S_3	1.46 a	0.30	0.67 cd	0.51 ab	53.33 de
K_3S_0	1.32 b	0.27	0.70 a-d	0.45 c-f	51.10 f
K_3S_1	1.08 c	0.25	0.72 a-c	0.46 b-e	52.67 ef
K_3S_2	1.47 a	0.30	0.71 a-d	0.48 bc	54.28 b-e
K_3S_3	1.48 a	0.26	0.77 a	0.56 a	55.38 bc
$LSD_{0.05}$	0.075	NS	0.053	0.05273	1.739
CV (%)	4.61	4.28	3.19	6.10	4.99

K_0=0 kgha^{-1}, K_1=20 kgha^{-1}, K_2=40 kgha^{-1}, K_3=60 kgha^{-1}

S_0=0 kgha^{-1}, S_1=10 kgha^{-1}, S_2=20 kgha^{-1}, S_3=30 kgha^{-1}

NS=Not significant

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

4.13 Zinc content in soybean plant

4.13.1 Effect of K on zinc content in soybean plant

Application of K showed significant variation on the zinc concentration (ppm) in soybean plant (Table 4.6). The highest zinc concentration in soybean plant (56.10 ppm) was recorded in K_1 (20 kg K ha^{-1}) treatment. On the other hand, the lowest zinc concentration in soybean plant (48.72 ppm) was recorded in the K_0 treatment where no K was applied.

4.13.2 Effect of S on zinc content in soybean plant

The effect of different doses of sulphur showed statistically significant difference on the zinc concentration (ppm) in soybean plant (Table 4.7). The highest zinc concentration among the treatments of sulphur (56.59 ppm) was observed in S_2 (20 kg S ha^{-1}) treatment. On the other hand, the lowest zinc concentration in soybean plant (51.53 ppm) was observed in the S_0 (control) treatment.

4.13.3 Interaction effect of K and S on zinc content in soybean plant

Significant effect of combined application of different doses of K and S fertilizers on the zinc concentration was observed in the soybean plant (Table 4.8). The highest concentration of zinc in the soybean plant (59.87 ppm) was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment which was statistically similar with K_1S_2 (20 kg K ha^{-1} + 20 kg S ha^{-1}) treatment combination. On the other hand, the lowest zinc concentration (42.55 ppm) in soybean plant was observed in K_0S_0 treatment.

4.14 Protein content in soybean seed

4.14.1 Effect of K on protein content in soybean seed

A statistically significant variation was observed in protein content in seed of soybean with different doses of potassium (Table 4.9). Among the different doses of potassium the highest protein content in seed (42.29%) was recorded in K_2 (40 kg K ha^{-1}) treatment which was statistically similar with K_3 (60 kg K ha^{-1}) treatment. On the other hand, the lowest protein content in seed (38.68%) was recorded in the K_0 treatment where no K was applied. Magen (1997) obtained the highest protein contents and nodulation with an application of 100 kg K_2O/ha.

Table 4.9 Effect of K on protein and oil content of soybean

Treatments	Protein content (%)	Oil content (%)
K_0	38.68 c	19.41
K_1	40.54 b	19.99
K_2	42.29a	20.40
K_3	42.20 a	20.31
$LSD_{0.05}$	1.393	NS
CV (%)	4.13	2.98

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$,K_3=60 $kgha^{-1}$

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

4.14.2 Effect of S on protein content in soybean seed

The effect of different doses of sulphur showed statistically significant variation on the protein content in seed of soybean (Table 4.10). The highest protein content in seed (42.15%) among different doses of S fertilizers was recorded with S_3 (30 kg S ha^{-1}) treatment which was statistically similar with S_2 (20 kg S ha^{-1}) treatment. On the other hand, the lowest protein content (39.22%) was observed in the S_0 (control condition) treatment. Gokhale *et al*. (2005) reported that application of 30 kg S ha^{-1} increased protein content in soybean seed over control. Tomar *et al.* (2000) reported that the highest protein content (41.29%) was recorded with the application of 50 kg S/ha regardless of sources.

***Table 4.10* Effect of S on protein and oil content of soybean**

Treatments	Protein content (%)	Oil content (%)
S_0	39.22 c	19.52
S_1	40.77 b	19.86
S_2	41.67 ab	20.53
S_3	42.15 a	20.60
$LSD_{0.05}$	1.115	NS
CV (%)	4.13	2.98

S_0=0 kgha^{-1}, S_1=10 kgha^{-1}, S_2=20 kgha^{-1}, S_3=30 kgha^{-1}

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

4.14.3 Interaction effect of K and S on protein content in soybean seed

Significant effect of combined application of different doses of K and S fertilizers on the protein content was observed in seed of soybean (Fig.9). The highest protein content in the seed (44.41%) was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment which was statistically similar with K_2S_3, K_3S_3 treatments (Appendix-VII). On the other hand, the lowest protein content (38.12%) in seed was observed in K_0S_0 treatment. Singh and Singh (1995) also found similar result with the application of 50 kg K_2O and 40 kg S ha^{-1}.

4.15 Oil content in soybean seed

4.15.1 Effect of K on oil content in soybean seed

A statistically insignificant variation was observed in oil content in seed of soybean with different doses of potassium (Table 4.9). Among the different doses of potassium, the highest oil content in seed (20.40%) was recorded in K_2 (40 kg K ha^{-1}) treatment. On the other hand, the lowest oil content in seed (19.41%) was recorded in the K_0 treatment where no K was applied. Deshmukh *et al.* (1994) obtained the highest oil content with an application of 60 kg K_2O/ha at Amravati and 90 kg K_2O/ha at Akola in Maharashtra State.

4.15.2 Effect of S on oil content in soybean seed

The effect of different doses of sulphur showed statistically insignificant variation on the oil content in seed of soybean (Table 4.10).The highest oil content (20.53%) in seed among different doses of S fertilizers was recorded with S_2 (20 kg S ha^{-1}) treatment. On the other hand, the lowest oil content (19.52%) was observed in the S_0 (control condition) treatment. Tomar *et al.* (2000) reported that the highest oil content (20.60%) was recorded with the application of 50 kg S/ha regardless of sources. Gokhale *et al.* (2005) reported that application of 30 kg S ha^{-1} increased oil content in soybean seed over control.

4.15.3 Interaction effect of K and S on oil content in soybean seed

Significant effect of combined application of different doses of K and S fertilizers on the oil content was observed in seed of soybean (Fig.10). The highest oil content in the seed (21.57%) was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment (Appendix-VII). On the other hand, the lowest oil content (18.49%) in seed was observed in K_0S_0 treatment. Singh and Singh (1995) also found similar result with the application of 50 kg K_2O and 40 kg S ha^{-1}.

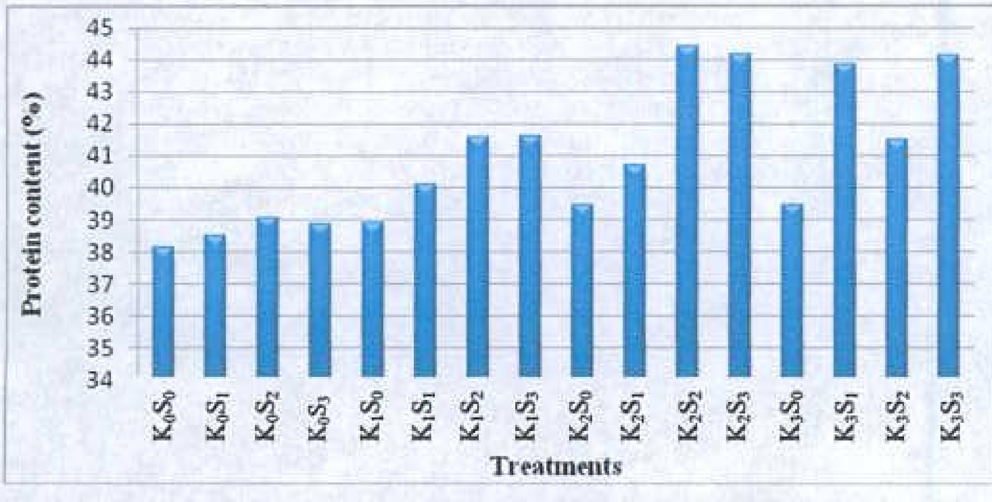

Fig.9. Combined effect of K and S on protein content (%) of soybean

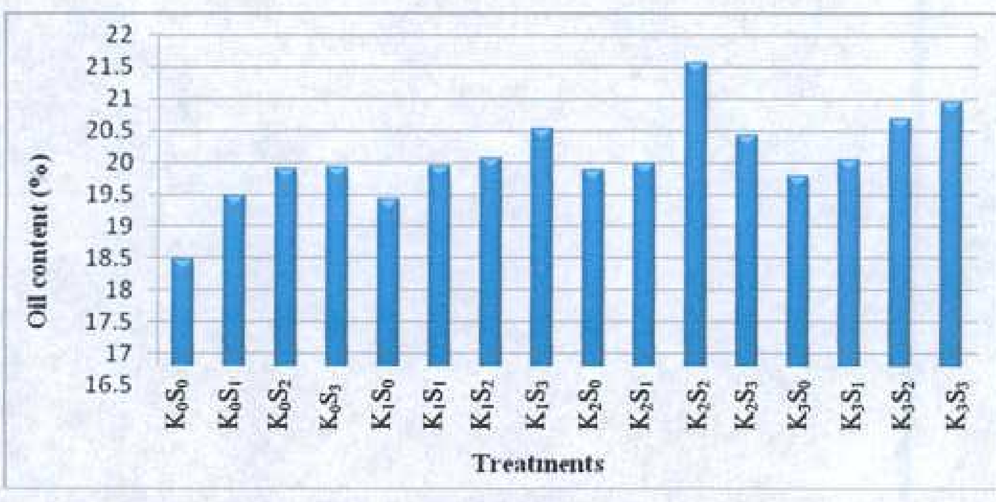

Fig.10. Combined effect of K and S on oil content (%) of soybean

4.16 Effect of potassium on nutrient status of the post harvest soil of soybean field

4.16.1 Effect of potassium on total nitrogen content in the post harvest soil of soybean field

A statistically significant variation was observed in nitrogen concentration in soil of soybean field with different doses of K (Table 4.11). Considering the different doses of K the highest nitrogen concentration in soil (0.117%) was recorded in K_2 (40 kg K ha^{-1}) which was statistically similar with K_1 and K_3 treatments. On the other hand, the lowest nitrogen concentration in soil (0.107%) was recorded in the K_0 treatment where no potassium was applied.

4.16.2 Effect of potassium on available phosphorus content in the post harvest soil of soybean field

A statistically insignificant variation was observed in phosphorus concentration in soil of soybean field with different doses of K (Table 4.11). Considering the different doses of K the highest phosphorus concentration in soil (0.00608%) was recorded in K_2 (40 kg K ha^{-1}). On the other hand, the lowest phosphorus concentration in soil (0.00441%) was recorded in the K_0 treatment where no potassium was applied.

4.16.3 Effect of potassium on available potassium content in the post harvest soil of soybean field

A statistically insignificant variation was observed in potassium concentration in soil of soybean field with different doses of K (Table 4.11). Considering the different doses of K the highest potassium concentration in soil (0.03713%) was recorded in K_2 (40 kg K ha^{-1}). On the other hand, the lowest potassium concentration in soil (0.02878%) was recorded in the K_0 treatment where no potassium was applied.

4.16.4 Effect of potassium on available sulphur content in the post harvest soil of soybean field

A statistically insignificant variation was observed in sulphur concentration in soil of soybean field with different doses of K (Table 4.11). Considering the different doses of K the highest potassium concentration in soil (0.00411%) was recorded in K_3 (60 kg K ha^{-1}). On the other hand, the lowest sulphur concentration in soil (0.00321%) was recorded in the K_0 treatment where no potassium was applied.

4.16.5 Effect of potassium on available zinc content in the post harvest soil of soybean field

A statistically significant variation was observed in zinc concentration in soil of soybean field with different doses of K (Table 4.11). Considering the different doses of K the highest zinc concentration in soil (1.871ppm) was recorded in K_3 (60 kg K ha^{-1}) which was statistically similar with K_2 treatment. On the other hand, the lowest zinc concentration in soil (1.786 ppm) was recorded in the K_0 treatment where no potassium was applied.

Table 4.11 Effect of K on the total N, P, K, S and Zn contents of the postharvest soil

Treatments	Total N (%)	Available P (%)	Available K (%)	Available S (%)	Available Zn (ppm)
K_0	0.107 b	0.00441	0.02878	0.00321	1.786 b
K_1	0.111 ab	0.00501	0.03043	0.00327	1.796 b
K_2	0.117 a	0.00608	0.03713	0.00379	1.856 a
K_3	0.114 ab	0.00561	0.03709	0.00411	1.871a
$LSD_{0.01}$	0.0083	NS	NS	NS	0.0368
CV (%)	3.19	3.12	2.28	3.56	2.18

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$, K_3=60 $kgha^{-1}$

NS=Not significant

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

4.17 Effect of sulphur on nutrient status of the post harvest soil of soybean field

4.17.1 Effect of sulphur on total nitrogen content in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizers showed a statistically significant variation in the nitrogen concentration in post harvest soil (Table 4.12). Among the different treatments, S_3 (30 kg S ha^{-1}) showed the highest nitrogen concentration (0.130%) in soil. The lowest nitrogen concentration (0.091%) in soil was observed in the treatment S_0 where no S fertilizer was applied.

4.17.2 Effect of sulphur on available phosphorus content in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizers showed a statistically insignificant variation in the phosphorus concentration in post harvest soil (Table 4.12). Among the different treatments, S_2 (20 kg S ha^{-1}) showed the highest nitrogen concentration (0.00589%) in soil. The lowest nitrogen concentration (0.00496%) in soil was observed in the treatment S_0 where no S fertilizer was applied.

4.17.3 Effect of sulphur on available potassium content in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizers showed a statistically insignificant variation in the potassium concentration in post harvest soil (Table 4.12). Among the different treatments, S_2 (20 kg S ha^{-1}) showed the highest potassium concentration (0.03509%) in soil. The lowest nitrogen concentration (0.03078%) in soil was observed in the treatment S_0 where no S fertilizer was applied.

Table 4.12 Effect of S on the total N, P, K, S and Zn contents of the post harvest soil

Treatments	Total N (%)	Available P (%)	Available K (%)	Available S (%)	Available Zn (ppm)
S_0	0.091 c	0.00496	0.03078	0.00234	1.769c
S_1	0.111 b	0.00488	0.03312	0.00323	1.641 d
S_2	0.118 b	0.00589	0.03509	0.00421	1.978a
S_3	0.130 a	0.00538	0.03444	0.00459	1.921b
$LSD_{0.01}$	0.0118	NS	NS	NS	0.0412
CV (%)	3.19	3.12	2.28	3.56	2.18

S_0=0 kgha^{-1}, S_1=10 kgha^{-1}, S_2=20 kgha^{-1}, S_3=30 kgha^{-1}

NS=Not significant

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

4.17.4 Effect of sulphur on available sulphur content in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizer showed a statistically insignificant variation in the sulphur concentration in post harvest soil (Table 4.12). Among the different treatments, S_3 (30 kg S ha^{-1}) showed the highest sulphur concentration (0.00459%) in soil. The lowest sulphur concentration (0.00234%) in soil was observed in the treatment S_0 where no S fertilizer was applied.

4.17.5 Effect of sulphur on available zinc content in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizers showed a statistically significant variation in the zinc concentration in post harvest soil (Table 4.12). Among the different treatments, S_2 (20 kg S ha^{-1}) showed the highest zinc concentration (1.978 ppm) in soil. The lowest sulphur concentration (1.641ppm) in soil was observed in the S_1 treatment.

Table 4.13 Interaction effects of K and S on the total N, P, K, S and Zn contents of the post harvest soil

Treatments	Total N (%)	Available P (%)	Available K (%)	Available S (%)	Available Zn (ppm)
K_0S_0	0.087 e	0.0041	0.0284	0.0013	1.51 i
K_0S_1	0.115 a-c	0.0043	0.0294	0.0033	1.54 h
K_0S_2	0.095 de	0.0045	0.0288	0.0040	2.08 ab
K_0S_3	0.130 ab	0.0050	0.0288	0.0045	2.04 bc
K_1S_0	0.095 de	0.0056	0.0291	0.0020	1.76 e
K_1S_1	0.097 c-e	0.0039	0.0300	0.0025	1.62 g
K_1S_2	0.122 ab	0.0061	0.0315	0.0036	2.06 a-c
K_1S_3	0.127 ab	0.0044	0.0311	0.0051	1.74 e
K_2S_0	0.091 e	0.0053	0.0358	0.0028	1.82 d
K_2S_1	0.112 b-d	0.0063	0.0361	0.0035	1.68 f
K_2S_2	0.135 a	0.0070	0.0401	0.0042	2.12 a
K_2S_3	0.130 ab	0.0060	0.0368	0.0049	1.82 d
K_3S_0	0.090 e	0.0051	0.0301	0.0035	2.01 c
K_3S_1	0.115 a-c	0.0050	0.0370	0.0036	1.72 ef
K_3S_2	0.118 ab	0.0062	0.0402	0.0053	1.67 f
K_3S_3	0.130 ab	0.0061	0.0410	0.0043	2.08 ab
$LSD_{0.01}$	0.0167	NS	NS	NS	0.05003
CV (%)	3.19	3.12	2.28	3.56	2.18

Ko=0 kgha^{-1}, K_1=20 kgha^{-1}, K_2=40 kgha^{-1}, K_3=60 kgha^{-1}

S_0=0 kgha^{-1}, S_1=10 kgha^{-1}, S_2=20 kgha^{-1}, S_3=30 kgha^{-1}

NS=Not significant

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

4.18 Interaction effect of potassium and sulphur on nutrient status of the post harvest soil of soybean field

4.18.1 Interaction effect of potassium and sulphur on total nitrogen content of the post harvest soil of soybean field

Significant effect of combined application of different doses of K and S fertilizers on the nitrogen concentration was observed in post harvest soil of soybean field (Table 4.13). The highest concentration of nitrogen (0.135%) in the post harvest soil was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment which was statistically similar with K_0S_3, K_1S_2, K_1S_3, K_2S_3, K_3S_2 and K_3S_3 treatment combinations. On the other hand, the lowest nitrogen concentration (0.087%) in the post harvest soil was observed in K_0S_0 treatment.

4.18.2 Interaction effect of potassium and sulphur on available phosphorus content of the post harvest soil of soybean field

Insignificant effect of combined application of different doses of K and S fertilizers on the phosphorus concentration was observed in post harvest soil of soybean field (Table 4.13). The highest concentration of phosphorus (0.0070%) in the post harvest soil was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) treatment. On the other hand, the lowest phosphorus concentration (0.0041%) in the post harvest soil was observed in K_0S_0 treatment.

4.18.3 Interaction effect of potassium and sulphur on available potassium content of the post harvest soil of soybean field

Insignificant effect of combined application of different doses of K and S fertilizers on the potassium concentration was observed in post harvest soil of soybean field (Table 4.13). The highest concentration of potassium (0.0413%) in the post harvest soil was recorded with the K_3S_3 (60 kg K ha^{-1} + 30 kg S ha^{-1}) treatment. On the other hand, the lowest potassium concentration (0.0284%) in the post harvest soil was observed in K_0S_0 treatment.

4.18.4 Interaction effect of potassium and sulphur on available sulphur content of the post harvest soil of soybean field

Insignificant effect of combined application of different doses of K and S fertilizers on the sulphur concentration was observed in post harvest soil of soybean field (Table 4.13). The highest concentration of sulphur (0.0053%) in the post harvest soil was recorded with the K_3S_2 (60 kg K ha^{-1} + 20 kg S ha^{-1}) treatment. On the other hand, the lowest sulphur concentration (0.0013%) in the post harvest soil was observed in K_0S_0 treatment.

4.18.5 Interaction effect of potassium and sulphur on available zinc content of the post harvest soil of soybean field

Significant effect of combined application of different doses of K and S fertilizers on the zinc concentration was observed in post harvest soil of soybean field (Table 4.13). The highest concentration of zinc (2.12 ppm) in the post harvest soil was recorded with the K_2S_2 (40 kg K ha^{-1} + 20 kg S ha^{-1}) which was statistically significant with K_0S_2 and K_3S_3 treatment. On the other hand, the lowest zinc concentration (1.51 ppm) in the post harvest soil was observed in K_0S_0 treatment.

Chapter 5

Summary and Conclusion

Chapter 5

SUMMARY AND CONCLUSION

An experiment was conducted at the Sher-e-Bangla Agricultural University Farm Dhaka-1207(Tejgaon series under AEZ No.28) during the *Rabi* season of 2011-2012 to study the "effects of potassium and sulphur on the growth, yield, protein and oil content of soybean". The soil was clay loam in texture having pH 6.60 and organic matter content of 0.84%.

The results of the experiment are stated indicated that:

Plant height was significantly affected by different levels of K and S. Plant height increased with increasing levels of K and S up to certain level. The individual application of K @ 40 kg ha^{-1} (K_2) produced the tallest plant (69.14 cm), whereas application of S @ 20 kg ha^{-1} (S_2) produced the tallest plant of 70.73 cm height. The tallest plant (74.40 cm) was found in K_3S_2 treatment, which was higher over control treatment (52.73 cm).

The individual application of K and S showed positive effect on the number of leaves per plant, number of primary branches per plant, number of pods per plant, number of seeds per plant, thousand seed weight (g), seed yield (t ha^{-1}) and straw yield (t ha^{-1}). All the plant characters increased with increasing levels of K and S up to certain level.

Like all other plant characters, seed yield of soybean was influenced significantly due to application of K and S. Seed yield was increased with increasing levels of K and S up to certain level. The highest grain yield (2.20t ha^{-1}) was found in plants receiving K @ 40 kg ha^{-1} and the lowest was recorded in K_0 treatment. The individual application of S @ 20 kg ha^{-1} produced the highest amount of grain yield (2.32 t ha^{-1}). The combined application of K and S had positive effect on grain yield of soybean. The highest grain yield of soybean (2.40 t ha^{-1}) was recorded in K_2S_2 treatment. The lowest yield (1.38 t ha^{-1}) was recorded in K_0S_0 treatment. Combined application of K @ 40 kg ha^{-1} and S @ 20 kg ha^{-1} produced higher grain yield compared to control treatment significantly.

Protein content in seeds of soybean was significantly increased due to the application of K and S. The range of protein content in seeds varied from 38.12% in K_0S_0 to 44.41% in K_2S_2 treatment. Application of K @ 40 kg ha^{-1} and S @ 20 kg ha^{-1} produced higher protein content in seed compared to control treatment significantly.

Oil content in seeds of soybean was significantly increased due to application of K and S. The range of oil content in seeds varied from 18.49% in K_0S_0 to 21.57% in K_2S_2 treatment. Application of K @ 40 kg ha^{-1} and S @ 20 kg ha^{-1} produced higher oil content in seed compared to control treatment significantly.

Nutrient contents (N, P, K, S and Zn) in plant samples were positively affected due to K and S fertilization. The interaction effect of K and S was also found remarkable. The N, P, K, S and Zn contents in plant samples varied from 0.86% in K_0S_0 treatment to 1.51% in K_2S_2 treatment, 0.15% in K_0S_0 treatment to 0.34% in K_2S_2 treatment, 0.42% in K_0S_0 treatment to 0.77% in K_3S_3 treatment, 0.29% in K_0S_0 treatment to 0.56% in K_2S_2 treatment and 42.55 ppm in K_0S_0 treatment to 59.87 ppm in K_2S_2 treatment, respectively. Nitrogen, Phosphorus, Potassium, Sulphur and Zinc contents in plant samples increased with increasing levels of K and S up to certain level.

Nutrient content in post harvest soil was also influenced by different levels of K and S application. The total N, available P, available K, available S and available Zn of post harvest soil varied from 0.087% to 0.135%, 0.0041% to 0.0070%, and 0.0284% to 0.0410%, 0.0013% to 0.0053% and 1.51 ppm to 2.12 ppm, respectively due to combined application of K and S at different levels. The addition of K and S not only increased the yield but also protect the soil from total exhaustion of nutrients.

Based on the results described above following conclusions could be made that:-
The higher growth and yield performance, protein and oil content of soybean were observed by the K_2S_2 treatment i.e., by the combined application of potassium and sulphur fertilizers @ 40 kg K ha^{-1} and 20 kg S ha^{-1} and also by K_2S_3 treatment combination.

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

The combined application of potassium and sulphur fertilizers @ 40 kg K ha^{-1} and 20 kg S ha^{-1} may be done in Tejgaon series under AEZ No.28 to get higher yield, protein and oil content of soybean and more research work on soybean should be done in different Agro- ecological zones of Bangladesh.

Chapter 6
References

Chapter 6

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Appendices

APPENDICES

Appendix I. Summary of analysis of variance of growth parameters of soybean as influenced by different level of potassium and sulphur

Source of variation	Degrees of freedom	Mean square				
		Plant height (cm)	Number of primary branches plant^{-1}	Number of leaves plant^{-1}	Number of pods plant^{-1}	Number of seeds plant^{-1}
Replication	2	0.316	0.001	0.004	0.354	2.716
Factor A	3	245.54*	3.736*	56.70*	565.58*	5143.51*
Factor B	3	261.09*	1.469*	47.76*	325.29*	2989.04*
AB	9	7.457*	0.102**	2.889*	8.121*	71.767*
Error	30	1.305	0.107	0.138	0.314	1.755

Appendix II. Summary of analysis of variance of yield attributes of soybean as influenced by different level of potassium and sulphur

Source of variation	Degrees of freedom	Mean square		
		1000 seed weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Replication	2	4.205	0.005	0.001
Factor A	3	45.195*	0.603*	0.525*
Factor B	3	27.685*	0.528*	0.429*
AB	9	3.866*	0.024**	0.083**
Error	30	0.186	0.015	0.011

Appendix III. Summary of analysis of variance of nutrient concentration of soybean plant as influenced by different level of potassium and sulphur

Source of variation	Degrees of freedom	Mean square				
		Total N (%)	Total P (%)	Total K (%)	Total S (%)	Total Zn (ppm)
Replication	2	0.001	0.004	0.001	0.003	0.984
Factor A	3	0.303*	NS	0.08**	0.047**	119.53*
Factor B	3	0.298*	NS	NS	0.033**	84.81*
AB	9	0.048**	NS	0.012**	0.002**	20.73*
Error	30	0.002	0.005	0.003	0.004	1.087

* Significant at 5 % level

** Significant at 1 % level

Appendix IV. Summary of analysis of variance of nutrient content of post harvest soil as influenced by different level of potassium and sulphur

Source of variation	Degrees of freedom	Mean square				
		Total N (%)	Available P (%)	Available K (%)	Available S (%)	Available Zn (ppm)
Replication	2	0.001	0.001	0.001	0.003	0.002
Factor A	3	0.001**	NS	NS	NS	0.022**
Factor B	3	0.010**	NS	NS	NS	0.221*
AB	9	0.002**	NS	NS	NS	0.102**
Error	30	0.002	0.004	0.002	0.004	0.002

Appendix V. Summary of analysis of variance of protein content and oil content of soybean as influenced by different level of potassium and sulphur

Source of variation	Degrees of freedom	Mean square	
		Protein content (%)	Oil content (%)
Replication	2	3.543	1.025
Factor A	3	33.783*	NS
Factor B	3	22.248*	NS
AB	9	5.595*	0.326**
Error	30	2.790	0.345

Appendix VI. Interaction effect of K and S on the plant height and yield components of soybean

Treatments	Plant height (cm)	Number of primary branches $plant^{-1}$	Number of leaves $plant^{-1}$	Number of pods $plant^{-1}$	Number of seeds $plant^{-1}$
K_0S_0	52.73 j	2.94 f	16.81 g	28.18 i	83.45 k
K_0S_1	55.78 i	3.11 ef	17.31 fg	30.21 h	90.63 j
K_0S_2	65.34 de	3.17 ef	18.43 ef	38.46 f	115.4 g
K_0S_3	61.25 g	3.13 ef	16.18 g	35.84 g	107.5 h
K_1S_0	57.70 h	2.95 f	15.89 g	31.86 h	95.58 i
K_1S_1	58.55 h	3.65 de	16.65 fg	42.80 de	128.4 f
K_1S_2	68.15 bc	3.95 cd	21.32 b-d	47.24 c	141.7 d
K_1S_3	66.20 cd	3.80 d	19.55 de	44.51 d	133.6 e
K_2S_0	64.12 ef	3.77 d	18.17 ef	42.38 e	127.2 f
K_2S_1	67.31 b-d	4.15 b-d	21.37 b-d	47.89 c	143.7 cd
K_2S_2	73.02 a	4.87a	25.49 a	53.80 a	159.6 a
K_2S_3	69.10 b	4.45 a-c	22.10 bc	50.93 ab	152.8 b
K_3S_0	62.74 fg	3.68 de	18.34 ef	39.17 f	117.5 g
K_3S_1	66.30 cd	4.00 cd	20.53 cd	47.41 c	142.3 d
K_3S_2	74.40 a	4.67 ab	23.15 ab	51.04 ab	155.1 ab
K_3S_3	67.80 bc	4.20 b-d	21.85 bc	49.06 bc	147.2 c
$LSD_{0.05}$	1.905	0.5455	1.779	1.911	3.636
CV (%)	7.89	7.22	6.95	5.39	8.12

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$, K_3=60 $kgha^{-1}$

S_0=0 $kgha^{-1}$, S_1=10 $kgha^{-1}$, S_2=20 $kgha^{-1}$, S_3=30 $kgha^{-1}$

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

Appendix VII. Interaction effect of K and S on protein and oil content of soybean

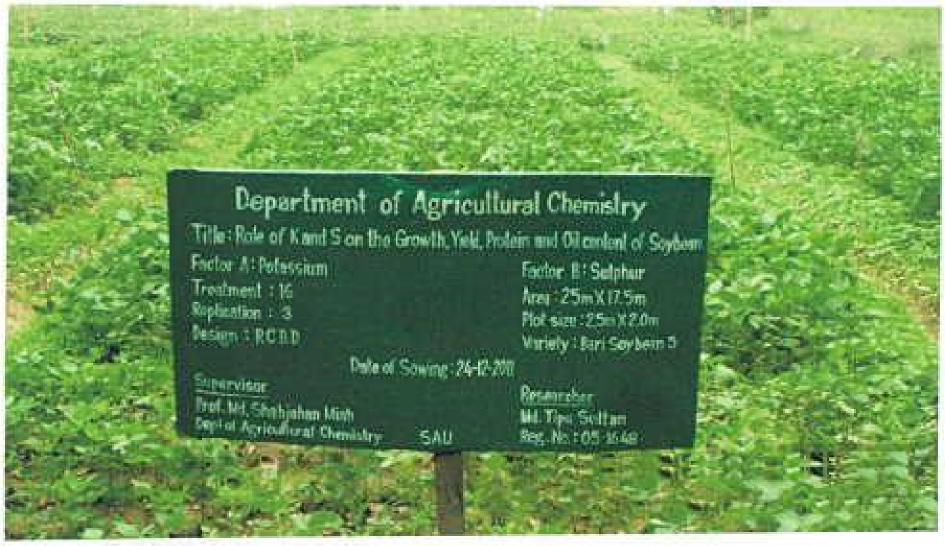
Treatments	Protein content (%)	Oil content (%)
K_0S_0	38.12 d	18.49 i
K_0S_1	38.51 d	19.48 h
K_0S_2	39.06 cd	19.90 e-g
K_0S_3	38.84 d	19.92 e-g
K_1S_0	38.90 d	19.42 h
K_1S_1	40.11 cd	19.94 e-g
K_1S_2	41.56 bc	20.07 e
K_1S_3	41.59 c	20.53 cd
K_2S_0	39.46 cd	19.88 fg
K_2S_1	40.69 cd	19.98 ef
K_2S_2	44.41 a	21.57a
K_2S_3	44.18 a	20.42 d
K_3S_0	39.44 cd	19.78 g
K_3S_1	43.86 ab	20.04 ef
K_3S_2	41.49 bc	20.68 c
K_3S_3	44.11 a	20.94 b
$LSD_{0.05}$	2.231	0.1582
CV (%)	4.13	2.98

Ko=0 $kgha^{-1}$, K_1=20 $kgha^{-1}$, K_2=40 $kgha^{-1}$, K_3=60 $kgha^{-1}$

S_0=0 $kgha^{-1}$, S_1=10 $kgha^{-1}$, S_2=20 $kgha^{-1}$, S_3=30 $kgha^{-1}$

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

Field view of the experiment



Appendix Figure I. Field view of experimental plot at 50 DAS

Appendix Figure II. Field view of experimental plot at 80 DAS