EFFECT OF PHOSPHORUS AND SULPHUR ON THE GROWTH, YIELD AND OIL CONTENT OF SOYBEAN

By

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CERTIFICATE

This is to certify that the thesis entitled **"Effect of Phosphorus and Sulphur on the growth, yield and oil content of Soybean"** submitted to the Department of Soil Science, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS) in SOIL SCIENCE**, embodies the result of a piece of *bona fide* research work carried out by **Fahmina Akter**, Registration Number: **04-01370,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: 06.06.2011
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DEDICATION

I DEDICATE MY THESIS TO MY PARENTS WHOSE EFFORTS AND EVER WILLING SUPPORT HAVE MADE THIS DREAM COME TRUE

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ABSTRACT

A field experiment was conducted at Sher-e-Bangla Agricultural University Farm, Dhaka during the period from December 2008 to April, 2009 to evaluate the effect of P and S on the growth, yield and oil content of soybean. BARI soybean -5 was used as test crop. The experiment comprised four levels of Phosphorus viz. 0, 15, 30, 50 kg ha^{-1} and four levels of Sulphur viz. 0, 10, 20, 40 kg ha^{-1}. Altogether there were 16 treatment combinations and laid out following the Randomized Complete Block Design with three replications.

Individual application of different levels of phosphorus and sulphur showed significant effect in relation to yield and yield attributes studied. Plant height, number of primary branch $plant^{-1}$, number of leaves $plant^{-1}$, stover yield, protein content and P,K, S content in plants, available N, P, K content in post harvest soil increased significantly up to 50 kg P ha^{-1} .On the other hand number of pods $plant^{-1}$, number of seeds $plant^{-1}$, thousand seed weight, grain yield, biological yield, oil content and N content in plant, available S content in post harvest soil were increased significantly by the application of P up to 30 kg P ha^{-1} . Effect of Individual application of P on the soil pH and the organic C content in post harvest soil was not significant.

The desired yield attributes viz. plant height, number of leaves $plant^{-1}$, number of pods $plant^{-1}$, number of seeds $plant^{-1}$, thousand seed weight, were increased significantly by the application of S up to 40 kg S ha^{-1} that were statistically similar with the results found at 20 kg S ha^{-1} . So its wise and economic to use S @20 kg S ha^{-1}. Protein content and total P, S content in plant, available N, P, K, S contents in post harvest soil were increased significantly at 40 Kg S ha^{-1}. On the other hand, no of primary branch $plant^{-1}$, grain yield, stover yield, biological yield, oil content, total N, K content in plant and organic C were increased at the rate of 20 kg S ha^{-1} in most cases.

Interaction effects of phosphorus and sulphur on yield attributes were increased significantly. Most of the growth, yield attributing parameters found to be increased significantly by the combined application of 30 kg P ha^{-1} and 20 kg S $ha^{-1.}$ The interaction effect of P and S on soil pH and organic carbon were not significant.

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Chapter I

Introduction

CHAPTER I
INTRODUCTION

Recognition of the importance of nutrient balance in crop production is an indirect reflection of the contribution of nutrient interactions to yield. As a result of intensive agriculture and enhanced use of nitrogenous fertilizers in Bangladesh, the crops have been shown to respond to the application of one or more of the other primary and secondary macronutrients such as P and S. the essentiality of P for the plant growth had been recognized in 1903 (Tamhane et al., 1970). Phosphorus deficiency is becoming wide spread and acute in many soils of Bangladesh. On the other hand, sulphur deficiencies are being observed in many parts of the country (Johiruddin et al. 1992, 1995).

Soybean (*Glycine max* L.) is an important and well recognized oil and protein containing crop of the world. It belongs to the family leguminosae, sub-family papilionidae and its chromosome number is 2n= 40 (Karpechonko, 1925).

Soybean is originating from the hot areas of South-East Asia, but more than 50% of its production today comes from the United States and South America. Soybean (*Glycine max*) was first introduced into the United States in 1765 (Soybean Research Advisory Institute, 1984).About 73,444 thousand hectares of land in the world is under cultivation of soybean and annual production is approximately 1, 91,993 million tons (FAO, 2008). As a grain legume crop it is gaining an important position in the agriculture of tropical countries including India, Sri Lanka, Thailand and Bangladesh. As a legume soybean has the capacity to form a symbiotic association with *Rhizobium japonicum* and able to fix 20% of the atmospheric nitrogen throughout the world annually (Franco, 1978). In Bangladesh, soybean is called the "Golden bean". Soybean grains contain 29.6-50.3 % protein, 13.5-24.2 % fat and 3.3-6.4% ash (Purseglove, 1984) and carbohydrate content is 24-26 % (Gowda and Kaul, 1982). It provides around

60% of the world supply of vegetable protein and 30% of the oil (Fehr, 1989). It is a good source of unsaturated fatty acids, mineral like Ca and P, vitamin A, B, C and D. It also meets up different nutritional needs. Furthermore, soybean oil is cholesterol free and is easily acceptable in our daily diet. 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.

Phosphorus is the second major essential nutrient element for plant growth. The most obvious effect of phosphorus is on plant root system, it promotes root formation and the formation of lateral fibrous and healthy roots which is very important for nodule formation and to fix atmospheric nitrogen. On the other hand Phosphorus is required for the formation of phosphides, nucleoprotein, nucleic acids, adenosine diphosphates and carbohydrates synthesis. Without adequate phosphorus application, all growth activities can be depressed. Phosphorus has significant effect on increasing the nitrogen content of legumes. Deficiency in phosphorus is now considered as one of the major constrains to successful production of legumes in Bangladesh.

Sulphur is being recognized as the 4^{th} 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 plow 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.

Among the various plant growth factors and their complex interdependence, the interaction of different element is quite important as these could be synergistic or antagonistic or merely additive. The interaction of P and S is quite expected in soil and plant system as both of these are adsorbed on similar sites on soil colloids and show similar composition of precipitation production with Ca, Fe and Al. Higher P and S demands of pulses and oilseeds have a definite bearing on their interrelationships. P and S interactions in soils of poor fertility may be more important (Aulakh et al., 1990; Marok and Dev, 1980). This study deals with the effect and interactive effects of applied P and S on growth, yield and oil content by BARI soybean-5 studied under SAU farm.

Keeping the above background in mind the present piece of research work was under taken with S and P dressing in soybean to address the following objectives:

1. To compare the growth and yield performance of soybean by using different doses of Phosphorus and Sulphur.
2. To find out the optimum doses of P and S for maximum growth, yield and oil content of soybean.

Chapter II

Review of Literature

CHAPTER II
REVIEW OF LITERATURE

Soybean is one of the most important oilseed crops of the world. Globally there is a little scope for increasing area under cultivation of soybean. It is necessary to improve the cultural practices of soybean as because the yield of this crop is not satisfactory. Sulphur is a vital part of all plant protein (Thompson and Troch, 1978). Phosphorus helps carbohydrate synthesis, root system development, and fruit and seed formation of plant (Brady, 1996). Information regarding the effect of P and S application on growth, yield, protein and oil content of soybean is scarcely available in Bangladesh. However an attempt has been made to review some of the available literature from home and abroad relevant to the present study in this chapter under the following headings:

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 Phosphorus and Sulphur Status in Soil

2.1.1 Phosphorus status

The available status of P in soils is often deficient for the growth of higher plants. There are three reasons for it. First, Phosphorus does not occur abundantly in soil as N. Total content of P in surface soils varies between 0.02 and 0.10% (Tisdale *et al.*, 1999). Second, the native P compounds are mostly unavailable for plant uptake. Third, when P fertilizer is added to soils, the element is soon changed to insoluble forms (Brady, 1996).

The quantity of total P in soils has little or no relationship to the availability of P to plants. Only a small portion of the P occurs in water soluble forms at one time. More than 90% of the soil P occurs in insoluble or fixed forms (Tisdale *et al.*, 1999). The P availability in soils varies greatly due to multiple factors like nature of parent material, degree of weathering, organic matter content soil pH, etc. The prevalence of Al, Fe in acid soils and Ca in calcareous soils makes the element unavailable to plant uptake. Application of phosphorus fertilizer is recommended for all soils and crops in Bangladesh (BARC, 1997).

2.1.2 Sulphur Status

Total S contents of the 0-10 cm layer in tropical Queens land soils ranged from 11 to 725 ppm sulphur (Probert, 1977). The total sulphur in peat soils varied from 0.42 to 3.67% with values below 1% associated only with fresh water derived peat (Lowe, 1986).

Total sulphur content of the soil of Aligarh, Agra and Mainpuri districts of Western Uttar Pradesh, India ranged from 105 to 189 ppm, with hill region soil having larger contents (Rattan *et al.,* 1995). Total soil sulphur content at different depths varied from 98 to 310 mg kg-' in Alfisols and from 100 to 387 mg kg^{-1} in Vertisols (Padmaja and Raju, 1992; Padmaja et al., 1993).

2.2 Phosphorus and Sulphur in Plants

2.2.1 Role of P in plants

Phosphorus is an important structural component of nucleic acids, coenzymes, nucleotides, phosphoproteins, phopholipids and sugar phosphates (Tisdale *et al.,* 1999). It is required for the synthesis of carbohydrates and formation of cell walls (Millar, 1955), Phosphorus increased the soybean oil content, pods per plant, grains per pod and kernel weight with wider spacing and increasing amount of P (Karim, 1977). For N-supplied soybean, a decrease in the P supply affected shoot growth relatively more than either root growth (Gassaman *et al.,* 1980).

Sulphur(S) occurs in soils in organic and inorganic forms, with the organic S accounting for >95% of the total S in most soils from humid and semihumid regions. Total sulphur status of soils varied between 23.1 to 369.6 mg kg^{-1} soils.

Total S in mineral soils may range from <02 μg g^{-1} in sandy soils to >600 μg g^{-1} in heavy texture soils. Organic soils may contain as much as 0.5% S. Most soils, however, contain 100 to 500 g S kg^{-1} soil' (Tabatabai, 1982).

A good supply of P is associated with increasing root growth (Tisdale *et al.*, 1999). Seed yields, seed weight and the number of pods per plant increased with increasing amounts of P (Shah *et al.*, 1986). The dry matter yield of whole soybean plant and N, P content and uptake at flowering and harvesting stages were significantly enhanced with increasing levels of P (Ninje and Seth, 1988).

2.2.2 Role of S in plants

Sulphur is required for the synthesis of proteins, vitamins Chlorophyll and also for the synthesis of the S containing amino acids such as cystine, cysteine and methionine which are essential components of proteins (Tiwari *et al.*, 1997). Sulphur containing ammo acids are also important intermediates in synthesis of other compounds within the cell. For example, S adenosyl methionine serves as a methyl donor in biosynthesis of many cellular components including chlorophyll, flavonoids and sterols. Sulphur is needed for the syntehsis of coenzyme A, which is involved in the oxidation and synthesis of fatty acids, the synthesis of amino acid (Tisdale *et al.*, 1999). S is known to stimulate root growth, seed and nodule formation (Tamhane *et al.*, 1970).

Sulphur is also major components of ferredoxin; the electron transfer molecule involved in photosynthesis and in reduction of oxidized compounds such as nitrite. Plant membrane structure and function also require S, sulpholipids being essential membrane compounds and intimately involved in organization of chlorophyll in chloroplast lamellae. Flavors, odors and toxic agents in some plants -can be linked to a range of S containing compounds (Smith and Siregar, 1983). S deficiencies may reduce yields, and can also severely reduce quality (mol % cysteine and methionine in protein) in grain and legumes by changing gene expression of storage proteins in developing seeds (Blagrove *et al.*, 1976; Randall *et al.*, 1979; Chandler *et al.*, 1983).

Sulphur deficiency affects both the yield and quality of food for human consumption. Sulphur fertilization improves nutritive quality of pasture legumes and grasses, and the marketability of several crops (Tiwari *et al.,* 1997). Plant metabolism depends on S and that S deprivation will cause basic metabolic dysfunction, which will result in reductions in crop yield and quality.

2.3 Extent of Phosphorus and Sulphur Deficiencies in Plants

2.3.1 Phosphorus deficiency

Phosphorus (P) does not occur as abundantly in soils as N and K. Total P in surface soils varies between about 0.005 and 0.15%. The average total P content of soils is lower in the humid south-east than in the praire and Western states (Tisdale *et al.,* 1999).

2.3.2 Sulphur deficiency

Sulphur is considered as one of the most limiting nutrients in Bangladesh agriculture particularly in the rice fields. About 44% of the cultivated lands in Bangladesh are estimated to be S deficient (Haque and Hobbs, 1978). The deficiency is particularly widespread in the semiarid and subhumid savanas of tropical America and Africa (Pasricha and Fox, 1993).

2.4 Acquisition of Phosphorus and Sulphur by Plant

2.4.1 Acquisition of Phosphorus

The content of different plant species vanes and more over, the quantity toper up by any given plant is affected by the available supply in the growth medium (Millar, 1955). One month after planting the leaves, stems, total tops of soybean contained 0.69, 0.58 and 0.65 percent phosphorus respectively. Ten days later and six days before the onset of the blooms the upper leaves, lower leaves, stems and total tops contained 0.74, 1.06, 0.76 and 1.05 percent phosphorus, respectively (Mederski, 1950). An increasing rate of uptake for the first 40-50 days and then fairly constant rate until leaf yellowing (Mederski, 1950).

2.4.2 Acquisition of Sulphur

Both the uptake and requirements for S differ greatly among species, among cultivars within a species and with stage of development of the crop (Gerloff, 1963; Thomposon *et al.*, 1970). At maturity, grain and leaves had the highest amount of sulphur, and the stem had the lowest. Fruiting pails^{-1}, i.e.; pod, husks and grain contained between 47 and 54 per cent of fertilizer sulphur (Kumar and Singh, 1980). Crops that commonly contain the largest amounts of S include the halophytes and most species of the cruciferae and liliacae families, whereas cotton, the legumes and tobacco are intermediate, and the small grains and maize *(Zea mays)* contain the least (Duke and Reisemauer, 1986).

Agricultural crops of USA are reported to contain S between 0.1 to 1.5% (Eaton, 1966) whereas crops of tropical areas generally contain 0.1 to 0.5 % (Whitehead, 1964). There are innumerable instances of plant S levels exceeding these ranges. For example, halophytes and other crops growing in saline soils may contain in excess of 3% (Thomas *et al.*, 1950).

2.5 Critical Levels of Phosphorus and Sulphur in Plants

2.5.1 Critical levels of Phosphorus

The critical limit of Olsen's P_20_5 determined by Scatter diagram as well as statistical procedure was 37.5 kg t ha^{-1} below which profitable responses to phosphate application can be expected from soybean (Gupta and Vyas, 1993). The critical level of available phosphorus for wheat ranged from 30 to 36 kg P_20_5 ha^{-1} with a critical level of 33 kg P_20_5 ha^{-1} (Sharma and Singh, 1993). The critical soil fertility limit of available P for maize was found to be 8.0 to 8.5 mg kg^{-1} soil with Olsen's extractant and AB-DTPA extractant, respectively (Singh and Bishnol, 1993). For loamy to clayey soils of upland crops (Modified Olsen Method) the critical levels of available phosphorus was 10 µg g^{-1} soil (BARC, 1997). For sandy soils of upland crops (Modified Olsen Method) it was 8 µg g^{-1} soil (BARC, 1997).

2.5.2 Critical levels of Sulphur

Critical levels for total S (whole plant analyzed) generally fall between 1.5 and 0.3 g kg^{-1}, and for SO_4^- between 0.1 and 0.3 g kg^{-1}. Soil S test interpretations have taken many forms, and include relating critical soil concentration to crop response parameters such as yield, plant S concentrations, or N/S ratio. Critical extractable SO_4^- levels vary greatly depending upon the extractant used and whether or not the investigation was preformed in the field or greenhouse; choice of crop has mino influence. Critical S concentration in wheat plants was 0.18 and 0.15 per cent in flag leaf and whole plants of wheat, respectively (Bansal, 1992). The critical limit of 0.15 per cent $CaCl_2$ extractantable S was about 12 mg kg^{-1} soils for wheat grain and straw (Gupta *et al.,* 1995). The critical soil available sulphur for young tea was 12 ppm with Morgan's reagent.

A critical level of 30 mg kg^{-1} of S, extracted by NH_4OAC, has been reported for corn *(Zea mays* L.) (Palaskar and Ghosh, 1985), rice *(Oryza saliva* L.) (Islam and Ponnamperuma, 1982) and cabbage *(Rrassica oleracea L.)* (Palaskar and Ghosh, 1981). By comparison, a critical level of about 10 mg kg^{-1} has commonly been reported for phosphate containing extractants (Bansal *et al.,* 1979; Islam and Pannamperuma, 1982; Bansal *et al.,* 1983; Palaskar and Ghosh, 1985; Islam and Bhuiyan, 1988). The critical limit for 0.5 M $NaHCO_3$ extractable S soil was 20 mg kg^{-1} (Arora and Sekhon, 1977; Tiwari *et al.,* 1983). The critical S levels in leaf tissues were 0.17% for rice, 0.20% for maize and wheat, 0.22% for chick pea and 0.25% for mustard and peanut (Tiwari *et al.,* 1983; Upadhyay, 1980).

2.6. Growth, Yield and Yield Attributing Characters

2.6.1 Effect of Phosphorus

Sharma *et al.* 2002 conducted a field experiment in Rajasthan, India in the rainy season of 1997 and 1998 to determine the effect of 3 P levels (30, 60 and 90 kg ha^{-1}) and 3 P sources. P at 60 kg ha^{-1} produced better yield, dry matter and yield components compared to 30 kg ha^{-1}.

Maurya and Rathi (2000) conducted a field study in Uttar Pradesh, India during 1995-97 to determine the effect of intercropping pigeon pea and phosphorus (P) fertilizer application on soybean growth and development. Treatments comprised: 4 cropping systems, 4 P rates (0, 30, 60 and 90 kg ha^{-1}). Application of P showed a positive effect on height of soybean, dry weight, root nodule, number of nodes per plant and other yield contributing characters up to the highest rate (90 kg P ha^{-1}). However, grain yield was maximum (4.67 q ha^{-1}, 54.11% higher than the control) with the application of 60 kg P ha^{-1}. The optimum level of P was 61.65 kg P ha^{-1} for sole soybean.

A field experiment was conducted during the kharif season of 1994 and 1995 in Indian Punjab, India, to evaluate the response of soybean (cv. PK 416) to the combined application of N (30, 60 and 90 kg ha^{-1}), P (40, 60 and 80 kg P_2O_5 ha^{-1}), K (30 and 60 kg K_2O ha^{-1}) and Zn (25 kg ha^{-1}). Gurkirpal *et al.* (2001) reported that the growth attributes and grain yield of soybean significantly increased with the application of the fertilizers. The highest numbers of pods per plant (68.9) and seed yield (24.8 q ha^{-1}) were obtained at the fertilizer combination NPKZn 90:80:60:25. The treatment NPK at 90:60:30 produced the highest 100-grain weight in soybean (16.6 g).

Bothe *et al.* (2000) evaluate the effects of P fertilizer (0, 25, 50, and 75 kg P_2O_5 ha^{-1}), spacing (30 x 10, 20 x, 10 and 30 x 5 cm) and P-solubilizers on the yield and yield components of a soybean-fenugreek cropping system were evaluated during 1995 at Pune, Maharashtra, India. All yield parameters increased with increasing levels of P fertilizer. P at 75 kg ha^{-1} recorded the highest values for plant height (71.20 cm), dry matter per plant (57.46 g) and straw yield (49.50 q ha^{-1}), while P at 25 kg ha^{-1} recorded the highest seed yield (42.83 q ha^{-1}).

The effect of P mobilizers and different levels of P on growth and yield of soybean (Glycine max cv. Co.1) was investigated in a field experiment conducted in Vamban, Tamil nadu, India, during summer and the kharif season of 1994 and 1995. The main plot consisted of 4 P mobilizers, i.e. pressmud, gypsum, enriched farmyard manure (FYM) and phosphobacteria. The subplot consisted of 3 levels of P, i.e. 40, 60 and 80 kg P_2O_5 ha^{-1}. Increased plant height, root length and number of branches per plant were observed at 80 kg P_2O_5 ha^{-1}. However, it was on a par with 60 kg P_2O_5 ha^{-1}. Ramasamy *et al.* (2000) reported that P application at 80 kg ha^{-1} recorded significantly higher number of pods per plant and was on a par with 60 kg ha^{-1}. P at 80 kg ha^{-1} recorded the highest grain yield of 1133 and 1396 kg ha^{-1} in summer and kharif, respectively, which was on a par with 60 kg ha^{-1}.

Soybean (*Glycine max* cv. Hutcheson) and rice plants, grown in a 1:1 rotation during 1998-2000, were treated with varying rates of phosphorus fertilizers (0, 20, 40, 80, and 120 lbs P_2O_5 $acre^{-1}$) at different times during the rotation (annually, or applied to rice or soybean only) in a field experiment conducted in Arkansas, USA. . Soybean yield was measured at maturity. Slaton *et al.* (2001) observed that compared to the untreated control, soil test P increased as P application rate increased. Soil test P was always highest when applied to both rice and soybean in the rotation. Application of P fertilizers to only rice or soybean increased soil test P, but not to the same extent as annual fertilizer applications. Tissue P concentration tended to increase with increasing P rates at one test location, but not at the other. Tissue concentrations tended to be highest when P was applied annually.

A field study was carried out by Kedar *et al*(.2001) at C. S. Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, India during 1995-97 to evaluate the phosphorus requirement of soybean under rainfed conditions. The treatment consisted of three cropping systems (pure pigeon pea, pure soybean and pigeon pea + soybean) and four rate of phosphorus (0, 30, 60 and 90 kg ha^{-1}). The yield and yield contributing characters in pigeon pea and soybean were statistically superior to application of 60 kg P_2O_5 ha^{-1} and numerically unto 90 kg P_2O_5 ha^{-1}. Application of 60 kg P_2O_5 ha^{-1} gave higher grain yield of pigeon pea by 2.85 q ha^{-1} (19.55%) and soybean by 3.19 q ha^{-1} (59.29%) over unfertilized plot.

Soybean was supplied with 0, 25, 50, 75 and 100 kg P_2O_5 ha^{-1} in a field experiment conducted in Rahuri, Maharashtra, India during the kharif season of 1996 on a Sawargaon soil series (Vertic Ustropept). An increase in applied P increased grain and straw yield, P uptake and soil available P. Bhakare and Sonar (2000) reported that the highest grain and straw soybean yields (32.1 and 64.9 q ha^{-1}, respectively), P uptake in grain and straw (12.9 and 14.6 q ha^{-1}, respectively) and soil available P (14.6 kg ha^{-1}) were recorded from the 100 kg P_2O_5 ha^{-1} treatment. The results showed that inorganic forms of P contribute to increased P availability and uptake in soybean and increased yields.

Rajendran and Lourduraj (2000) conducted a field experiments at Tamil Nadu Agricultural University, Coimbatore, India during the summer (January-April) and kharif (June-September) seasons of 1994 and 1995 in a split plot design. The main plot consisted of three levels of irrigation, and three levels of plant population. The subplot treatments consisted of three levels of phosphorus (80, 100 and 120 kg P_2O_5 ha^{-1}). The result revealed that P level of 100 kg P_2O_5 ha^{-1} is promising in obtaining maximum yield in soybean.

Two field experiments were carried out at Aborgwan-Al-Bdrashin, Giza, in 1997 and 1998 to study the response of soybeans cv. Crawford to three rates of phosphorus fertilizer (20, 40 and 60 kg P_2O_5/fed), Osman *et al.* (2000) reported that yield increased with increasing P rate.

In field trials in 1995/96 and 1996/97 at Kanpur, Uttar Pradesh, India, soybeans cv. JS 72-44 were given 0, 30, 60 or 90 kg P ha^{-1}. Mourya B. M. (1999) observed that yield increased with increasing P rate up to 60 kg ha^{-1} in case of intercropping with Pigeon pea but for sole cropping the height yield was obtained at 30 kg ha^{-1}.

Casanova, E. (2000) conducted a field experiment in 1997-98 on loamy acid (pH 4.5) soils with high potential for soybean production and low to medium levels of available P, K and Ca at Palo Seco, Venezuela, soybeans cv. FP-3 were given 0-70 kg P ha^{-1} and 0-135 kg K ha^{-1}. The combination of 70 kg P ha^{-1} and 108 kg K ha^{-1} produced the highest soybean grain yields. In 1997, where P was not applied the leaf P concentration was at the deficiency level, and the highest P concentration was reached with 60 kg P ha^{-1}. The 18 kg K ha^{-1} treatment produced K leaf concentrations within the sufficiency range.

Sridhara *et al.* (1998) conducted a field experiment at Bangalore in 1993 to study the effects of 0-100 kg P_2O_5 ha^{-1} on soybeans cv. Hardee and KHSb-2. The highest agronomic efficiency (increase in seed yield per unit fertilizer) was obtained with 80 kg P_2O_5 ha^{-1}, while the physiological efficiency of nutrients (unit additional seed yield per unit additional nutrient uptake) tended to decrease with the increase in phosphorus levels. Differences in agronomic and physiological efficiency between cultivars were not statistically significant.

In a field experiment during the rainy seasons of 1992 and 1993 at Chhindwara, Madhya Pradesh, India, soybeans cv. JS 72-44 were given 20, 40 or 60 kg P ha^{-1} as single super phosphate or diammonium phosphate (DAP) drilled with seed or separately or broadcast. Sitaram *et al* (1999) observed that yield was greatest with 60 kg P.

Sanjeev *et al* (2005). Conducted a study in Haryana, India, during the rainy season of 2000 to assess the effects of nitrogen and phosphorus fertilizers on the nutrient uptake and yield of soybean (cv. PK 416). Treatments comprised: 0, 20, 40 and 60 kg N ha^{-1}, and 0, 40, 60 and 80 kg P ha^{-1}. P content in seed and Stover increased with increasing N and P rates up to 60 kg ha^{-1} and 80 kg ha^{-1}, respectively. Of the total nutrients accumulated by the crop, the seeds and the remaining by stover retained 87.1% of N and 68.1% of P. Maximum uptakes P in seeds, stover and in the whole plant were recorded upon treatment with 80 kg P ha^{-1}. Soybean seed yield was highest with 80 kg P ha^{-1} treatment (22.82 q ha^{-1}), followed by 60 kg P ha^{-1} (22.58 q ha^{-1}), and were significantly superior to the 20 kg P ha^{-1} and control treatments.

Shipra and Pal , (2005) conducted a field experiment during 2002 and 2003 on medium black soils of Madhya Pradesh, India to study the effect of graded levels of phosphorus (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) on grain yield, quality, economics and balance sheet of soybean cv. JS-335. Application of P_2O_5 significantly increased the grain yield, protein content, oil content, net return and benefit: cost ratio up to 60 kg ha^{-1}, which was at par with 90 kg ha^{-1}. The highest removal and gain were recorded with the application of 90 kg P_2O_5 ha^{-1}.

An experiment was conducted during the kharif season of 1995 and 1996 to study the effect of Bradyrhizobium japonicum and phosphorus solubilizing bacterium (PSB; Bacillus polymyxa [Paenibacillus polymyxa]) alone or in combination with different levels of phosphorus (13.10, 19.65 and 26.20 kg ha^{-1}) on soybean at Gwalior, Madhya Pradesh, India. Increasing levels of phosphorus up to 26.20 kg ha^{-1} also improved the seed yield and quality parameters. Jain and Trivedi (2005) found that from all different combinations, application of 19.65 kg P ha^{-1} with Bradyrhizobium japonicum and PSB registered higher seed yield, oil yield and protein content, resulting into the higher return and cost benefit ratio over the independent application of 26.20 kg P ha^{-1}, and thus 6.55 kg P may be saved without affecting the yield.

Silva *et al*. (2004) evaluated the effects of phosphate fertilizer levels and different base saturations on the growth of soybean in a savannah soil under greenhouse conditions were determined. Six soybean plants were grown in pots with 3 liters of soil for 50 days. A 4x4 factorial experimental design with 4 replicates was used. Treatments included the application of 4 P levels (0, 30, 60, 90 mg.kg^{-1} of soil) in 4 base saturations of the soil (20, 40, 60, 80%). The results showed that P application and the interaction P x base saturation increased the growth of soybean. The highest growth was obtained by the application of 67 mg P. kg^{-1} in 54.2% base saturation of the soil.

A pot trial was conducted to investigate the effects of soil types and levels of N (0, 15 and 25 kg ha^{-1}) and P (0, 40 and 50 kg ha^{-1}) on yield, nodulation and nutrient uptake of soybean grown on tropical soils, collected from 6 locations in Nigeria. . Azeez and Adetunji (2003) found that the interaction between soil type and N or P also indicated that forest soil with 25 kg N ha^{-1} or 50 kg ha^{-1} had significantly higher values for the soybean performance parameters investigated. In general, the combined application of 25 kg N ha^{-1} and 50 kg P ha^{-1} appeared optimum for soybean cultivation

Field experiment was conducted by Sonar and Bhakare (2004) during 1996-97 to investigate the influence of P application on yield, P uptake and nutrient status of soil after soybean-wheat cropping sequence in an Inceptisol. Soybean (cv. MACS-124) was sown and received five levels of P (0, 25, 50, 75 and 100 kg P_2O_5 ha^{-1}) with uniform application of recommended dose of N (25 kg N ha^{-1}). The application of graded levels of phosphorus to soybean-wheat sequence cropping increased the grain and straw yields of both soybean and wheat. The total P uptake in soybean (grain and straw) was increased with the P applications and highest uptake was attained on application of 100 kg P_2O_5 ha^{-1} that was significantly superior to all other treatments. The organic carbon content in soil after harvest increased with the increase in phosphorus levels to soybean. The available P status in soil increased with the increase in the application of phosphorus levels for Soybean. The increased P applications also increased the available K status and were highest for 75 and 100 kg P_2O_5 ha^{-1} (412 and 420 kg P_2O_5 ha^{-1}, respectively) and were at par at each other.

Field experiments were conducted by Sundari A. (2003) during kharif in Periyaru-Vaigai Command area (Tamil Nadu, India) to study the effects of phosphorus levels (0, 40, 80 and 120 kg ha^{-1}) on the growth of soybean cv. CO1. Application of 80 kg P_2O_5 ha^{-1} showed the high growth parameters compared to other treatments.

Application of 20 kg P ha^{-1} significantly increased the pod length, 100 kernel weight and pod yield of soybean (Reddy and Gajendragiri, 1989). Phosphorus application resulted significant increase in number of pods $plant^{-1}$, number of seeds pod^{-1} and 100 kernel weight of soybean. Phosphorus also increased significantly pod and seed yield as compared to control (Jana *et al.*, 1990). The grain and straw yields of soybean were increased significantly due to phosphorus levels upto 30 kg P ha^{-1} (Singh and Bajpai, 1990).Increasing rates of phosphorus increased S contents in grain (Vijoy and Chauhan, 1987). Nitrogen concentration in grain increased significantly at 46 kg P ha^{-1}. Phosphorus content in grain increased due to application of phosphorus compared with control treatment (22.9 kg to 45.8 kg).

The beneficial effect of phosphorus on number of pods per plant increased (Rajput and Verma, 1982). Seed yield of mungbean increased significantly up to 20 kg P_20_5 ha^{-1} (Rajkhowa *et al.*, 1992). Dry matter yield of whole soybean at flowering and harvesting stages were significantly enhanced with increasing levels of phosphorus (Ninje and Seth, 1988). Total dry matter weight production of chickpea increased with increasing phosphorus rate (Parihar and Tripathi, 1989). Phosphorus application had significant influence on the dry matter yield, its concentration and uptake by green gram. Phosphorus addition increased with straw yields of mungbean on soils form various locations of Bangladesh. Dry matter of mustard *(Brassica juncea)* increased significantly with the application of S and P (Singh *et al.*, 1986).

Total dry matter of mustard *(Brassica juncea)* increased significantly with the application of phosphorus (Singh *et al.*, 1986; Sharma and Kamath, 1990).

Phosphorus application increased the plant height of green gram on 45th day and at harvest, dry matter yield of above ground parts during 30 to 60 days of growth were significantly increased in black gram Vigna mango by P application (Khandaker *et al.,* 1985). The percentage of increased by application of phosphorus at the rate of 30 kg P_2O_5 ha^{-1} over control was 45 for the straw yield (Khandker *et al.*, 1985; Sacchidanand *et al.,* 1980). Application of 69 kg P_2O_5 ha^{-1} 40 day after sowing to reproductive stage significantly increased leaf area index of soybean. Total dry matter at harvest was maximum with 69 kg P_2O_5 ha^{-1} (Upadhyay *et al.*, 1988).

Application of 40 kg P_2O_5 ha^{-1} significantly increased the leaf area index of groundnut. Higher level (80 kg P_2O_5 ha^{-1} had no advantage over 40 kg P_2O_5 ha^{-1}. Straw yield of chickpea increased significantly with increasing levels of diammonium phosphate upto 15 kg ha^{-1} (Sarawgi and Singh, 1988). Application of 224 kg P ha^{-1} increased the dry matter yield of both leaves and stems of soybean (Islam, 1964). Application of 15 kg P_2O_5 ha^{-1} significantly increased plant height, dry matter accumulation over the control *(Brassica juncea)* were increased significantly by increasing levels of phosphate 120 kg P_2O_5 ha^{-1} (Patel and Shelke, 1999). Application of 60 kgha^{-1} phosphorous fertilizer and 30 kg ha^{-1} triacontanal granules significantly increased the growth parameters of mustard (Sumeriya *et al.*, 2000).

2.6.2 Effect of Sulphur

Sulphur is a secondary nutrient occurring in soil both in inorganic and organic forms. The average sulphur content of the earth's crust is 0.06-0.10% (Tisdale *et al.,* 1999). The main sulphur bearing minerals are gypsum ($CaSO_4$, 21-120), epsomite ($MgSO_4$, $7H_20$), mirabilite (Na_2SO_4, $10H_20$), Pyrite (FeS_2) and Sphalerite (ZnS). Sulphur requirement of oilseeds, on an average is quite high as compared to other crops. It plays, therefore a significant role in quality and seed development in oilseed crops (Das and Das, 1994). Application of 75 kg S ha^{-1} in the form of SSP (Single super phosphate) proved to be the best treatment for increasing and improving the quality of the soybean seed yield (Sharma *et al.,* 2001). 45 kg S ha^{-1} recorded a significant increase in dry matter and seed yield (Babhulkar *et al.,* 2000).

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^{-1}) in the presence and absence of *Bradyrhizobium.* Arunageeta *et al.* (2006) revealed that the highest soyabean 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^{-1}), uptake of N (13 g $plant^{-1}$) and S (0.46 g $plant^{-1}$) were recorded with 30 kg S ha^{-1}. Similarly, *Rhizobium* inoculated plant recorded higher BNF, seed yield and uptake than uninoculated plants.

Manchanda *et al.* 2006 conducted a field experiment in Ludhiana, Punjab, India, during 2003-04 on a loamy sand soil deficient in available S (7.37 mg kg^{-1} soil) to study the effects of S fertilizer (0, 7.5, 15.0 and 30 kg S ha^{-1} as gypsum) on the yield and nutrition status of crops under a soyabean (cv. SL 295)-wheat (cv. PBW 343) system. The grain yield of soyabean increased by 23.1 and 30.5% over the control with application of 7.5 and 15.0 kg S ha^{-1}, respectively. The total biological yield of these crops also increased significantly with S application. However, the harvest index of both crops was not significantly affected. The availability of Zn, Cu, Fe and Mn in soil, and the concentrations and uptake of these nutrients for both crops increased significantly due to S application.

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 *et al.* (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 Sha^{-1}.

A field experiment was conducted by Arshad *et al.* (2005) in New Delhi, India to assess the growth characteristics, seed and oil yield of two cultivars of soyabean (G. max), i.e. PK-416 (V1) and PK-1024 (V2), in relation to sulfur and nitrogen nutrition. Six combinations (T1-T6) 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 soyabean 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 T6 (having 40 kg S and 43.5 kg N ha^{-1}). Seed and oil yields were increased by 90 and 102% in V1, and 104 and 123% in V2, respectively, compared to the control i.e. T1 (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 soyabean cultivars by enhancing their growth.

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^{-1}) on soybean (cv. MACS 124) in Maharashtra, India during *kharif* 2002-2004. Application of increasing S levels up to 30 kg ha^{-1} increased the seed yields over the control. Thus, the highest soybean yield of 25.1 q ha^{-1} was observed at 30 kg S ha^{-1}. Treatments with 40 and 50 kg S ha^{-1} slightly reduced the yields as the soil under study was marginally low in S content (9.6 mg ha^{-1}) which showed responses to lower S levels. The highest increase in monetary returns over the control (without S) was Rs. 4290 ha^{-1} under the 30 kg S ha^{-1} treatment. Each level of S application up to 30 kg ha^{-1} significantly increased the uptake over the lower levels. The highest N and S uptake by seeds were observed at 30 kg S ha^{-1} (181.0 and 41.3 kg ha^{-1}, respectively) and higher levels of 40 and 50 kg S ha^{-1} 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^{-1}. Thereafter, 40 and 50 kg S ha^{-1} 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.

The effects of S rate (0, 10, 20 or 30 kg ha^{-1}) and source (50% through ammonium sulfate + 50% through elemental S or compound fertilizer 13-33-0-15S) on the performance of soyabean (cv. JS 335) grown on Typic Haplusterts and on soil properties were studied in Indore, Madhya Pradesh, India, during 2002-03. Sharma *et al.* (2004) observed that the values of the evaluated parameters increased as the S rate increased and when the compound fertilizer was applied. Thus, 30 kg S ha^{-1} supplied through 13-33-0-15 S resulted in the highest number of nodules per plant (113.6), nodule fresh weight (1.082 g per plant), nodule dry weight (0.341 g) number of pods per plant (50.0), number of seeds per pod (2.08), 100-grain weight (11.94 g), grain yield (1747 kg ha^{-1}), straw yield (2214 kg ha^{-1}), protein content (39.3%), oil content (20.19%), and N (109.7 kg ha^{-1}), P (4.06 kg ha^{-1}), K (41.0 kg ha^{-1}), S (12.40 kg ha^{-1}) and Zn (0.28 kg ha^{-1}) uptake. This treatment also registered the highest soil P_2O_5 (19.4 kg ha^{-1}), K_2O (522.0 kg ha^{-1}), S (8.80 kg ha^{-1}) and Zn (2.79 kg ha^{-1}) contents. The rates and sources of S did not significantly vary for their effects on soil pH, EC [electrical conductivity], organic C, and available N after harvesting.

Sangale *et al.* (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^{-1}) 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^{-1} gave highest yield.

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^{-1}), 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 *et al.* (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^{-1} 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.

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^{-1}) 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^{-1} 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^{-1}, followed by S at 30 kg $^{-1}$.

A pot culture experiment was conducted by Praharaj *et al.* (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^{-1} 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%.

The yield response of soybeans to sulfur application was evaluated by *et. al.* (2001) at 2 sites (Bandera, Santiago del Estero, and Gral. Pico, La Pampa) in Argentina during 2000-01. Both sites were selected as deficient environments and initial soil levels of sulfur were 11.6 and 6.7 ppm, respectively. Five doses of sulfur between 0 and 80 kg SO_4^- ha^{-1} were applied at Bandera and between 0 and 40 kg $SO_4^-ha^{-1}$ at Dorila. The varieties used were A-6001 PR at Bandera and Nidera A-4100 at Dorila. Singh *et al.* found that Sulfur fertilization had no significant effect on soybean yield.

A field experiment was conducted 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^{-1}) and 3 sources, i.e. gypsum, pyrite and elemental sulfur, along with an absolute control. Tomar *et al.* (2000) reported that the highest seed yield, protein and oil content of 2257 kg ha^{-1}, 41.29% and 20.51%, respectively, were recorded with the application of 50 kg S ha^{-1} 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^{-1} increased with 30 kg ha^{-1} of sulphur.

Kulhare and Kaura.(2000) conducted an experiment on wheat-soyabean sequential cropping systems (1987-91) to study the effects of regular, residual and cumulative S levels (0, 10, 20 and 30 kg gypsum ha^{-1} and 20 kg ammonium sulfate ha^{-1}) on deep black soils (Vertisol) of Madhya Pradesh, India. P and S uptake by soyabeans and the physicochemical properties of Vertisols at the end of the third cropping sequence were evaluated. S at 10 and 20 kg a.i ha^{-1} significantly increased P and S uptake by soyabean seeds and S uptake by stover compared with the control. P and S uptake at 20 kg S ha^{-1} were significantly higher than at 30 kg S ha^{-1}, whereas the difference between 10 and 20 kg S ha^{-1} was non-significant. Sub-surface soil pH was significantly higher at 30 kg S ha^{-1} than at 20 kg S ha^{-1}. The availability of N, K and S in the soil surface increased with S application while ammonium sulfate was better than gypsum for P and S availability in the soil and soyabean nutrient uptake.

2.7 Effect of phosphorus and sulphur interaction

Research work with phosphorus and sulphur interaction is limited. However, some of the literatures related to this study are cited here:

Jayesh *et al.* (2000) conducted a field experiment in Punjab, India, during 1993-94 and 1994-95, to evaluate the response of obi sarson (B. napus subsp. oleifera var. annua [B. napus var. oleifera]) cv. GSL 1 and soyabean (G. max) cv. PK 416 in sequential cropping to combinations of P (at 30, 60 and 90 kg ha^{-1}) and S fertilizers (at 0, 20 and 40 kg ha^{-1}). The application patterns of P were residual, direct and cumulative. Direct application of P yielded the best results. Both crops grown under residual P application had less yield compared to those grown under direct P. Direct application of P at 60 kg ha^{-1} resulted in higher yields of both crops in the cropping system. Application of P to soyabean alone gave higher agronomic efficiency than application to gobhi sarson. Application of 60 kg P ha^{-1} to either of the crops produced lower physiological efficiency than application of 30 + 30 kg P ha^{-1} to both the crops. Both crops responded to S application only up to 20 kg ha^{-1}.

Dwivedi and Bapat (1996) conducted a pot experiment to find out the effect of P and S on Soyabeans cv. Gaurav. Different S and P rates were given in this pot trial. Dwivedi and Bapat (1996) Uptake and concentrations of N, P and K are tabulated for different growth stages of soybean. Nutrient contents increased with increasing S and P rates.

Dwivedi *et al.*(1999) conducted a field experiment to find out the effect of P and S on Soyabeans cv. Gaurav grown at Jabalpur, Madhya Pradesh in kharif [monsoon] 1990/91 and 1991/92, were given 0-120 kg P_2O_5 and 0-80 kg S ha^{-1}. Seed yield was highest with 80 kg P_2O_5 and 60 kg S ha^{-1}. Data on leaf area ratio, specific leaf weight, specific leaf area and dry matter production are tabulated.

Soyabean (*Glycine max*) seeds contain isoflavones that have positive impacts on human health. The objective of this study was to determine the impact of pre-plant mineral fertilization on isoflavone, oil and crude protein (CP) concentrations, and seed yield of field-grown soyabean. The effects of potassium (0, 50, 100, and 150 kg K ha^{-1}), phosphorus (0, 25, 50, and 75 kg P ha^{-1}), sulfur (0, 15, 30, 45 kg S ha^{-1}), and boron (0, 1.5, 3.0, and 4.5 kg B ha^{-1}) were tested separately, each with two soyabean cultivars ('Golden' and 'Grand Prix') grown in replicated trials at Sainte-Anne-de-Bellevue, Quebec, Canada in 2002/03. Seed total and individual isoflavone concentrations were determined by high-performance liquid chromatography. Seed yield, 100-seed weight, and oil and CP contents were determined concurrently. Seguin and Zheng(2006) found that across years and cultivars, no fertilizer treatments effects were observed for most variables. This overall lack of response to fertilizers was attributed to the relatively high initial fertility of the sandy loam and sandy clay loam soils used.

Ahmad *et al.* 2005 conducted a research work on Soybean to evaluate the effect of P and S and Mo. The effects of S (0, 40, 80 or 120 mg per pot), P (0, 40 or 80 mg per pot) and Mo on the quality of soyabean (cv. Bragg) grains were studied. Increasing the level of S increased the crude protein, cystine, cysteine and methionine contents. Methionine was the most abundant among the sulfur-containing amino acids, followed by cystine and cysteine. The contents of reducing sugar and nonreducing sugar, and the total sugar content increased with 40 and 80 mg S; these parameters, however, decreased when 120 mg S per pot was applied. The nonreducing sugar content was slightly higher than the reducing sugar content. The total sugar content increased when 80 mg S was applied at all levels of P, but decreased when S was supplied with 120 mg P. In the absence of S, 40 mg P increased the total sugar percentage, whereas 80 mg P reduced the total sugar content. A higher total sugar content was obtained with 120 mg P over the lower P rates. The methionine content increased with 40 mg P, but decreased with 80 mg P. Mo significantly reduced the cystine and cysteine contents. The results indicated that the application of S and P to soils with marginal status improved soyabean grain yield and quality. However, the application of Mo when it is not deficient in soil may deteriorate the quality of grains by reducing the amount of S-containing amino acids.

Tomar *et al.* (2004) conducted a field experiment during the 1999 kharif season in Madhya Pradesh, India, to study the effect of P and S fertilizers and rhizobium (*Rhizobium japonicum* [*Bradyrhizobium japonicum*]) inoculation on the growth, yield and quality of soyabean. The treatments comprised: 0, 30 and 60 kg P ha^{-1}; 0, 20 and 40 kg S ha^{-1}; and with and without *R. japonicum* inoculation. All the treatments increased plant height, leaf area index, number of root nodules per plant, main root length, dry matter accumulation, number of pods per plant, number of seeds per pod, test weight, seed and straw yield, and protein and oil contents..

Dwivedi *et al.*(2001) studied to evaluate the effect of S and P fertilizer application on Zn, Mn, Fe, and Cu in soyabean in Vertisol 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^{-1} compared with the control. On the other hand, a deleterious effect with successive P 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 P application exhibited a synergistic relationship for soyabean especially that grown on S and P deficient soil.

Majumdar *et al.*(2001) conducted a field experiment in Meghalaya, India, during the rainy (kharif) seasons of 1998-99 on a phosphorus (P) and sulfur (S) deficient Hapludalf, to evaluate the influence of different levels of P and S on yield, yield attributes, nutrient uptake and seed quality of soyabean (*Glycine max).* All the P and S levels significantly increased the grain and straw yields, pods per plant, 100-seed weight, oil and protein content and their yields and N, P and S uptake by soyabean. The N: S ratio in the seed reduced significantly by both P and S application. Interaction of P and S was also significant for all the parameters studied. Application of 60 kg P_2O_5 along with 40 kg S ha^{-1} was the optimum rate of P and S to obtain the highest yield.

Dwivedi *et al.* (1998) studied the effects of sulfur and phosphorus fertilizers (0, 25, 50, and 75 mg kg^{-1}) on the content and uptake of secondary nutrients by soyabean cv. Gaurav in a pot experiment. Measurements were taken at the four-node and flowering stages. Calcium content and uptake increased with increasing

P and S rates up to 50 mg kg^{-1}; at 75 mg kg^{-1}, calcium content and accumulation decreased. Magnesium uptake increased with the application of S and P up to 50 mg kg^{-1}; 75 mg magnesium kg^{-1} did not significantly affect the concentration and uptake of this nutrient. At harvest, calcium and magnesium uptake was higher in straw than grains. Sulfur uptake increased with the increase in S and P up to 50 mg kg^{-1}. At harvest, sulfur uptake was higher in grains than straw.

Phosphorus and sulphur application increased the yield components of the soybean. Increasing levels of phosphorus and sulphur significantly increased branch $plant^{-1}$ Pod length, straw and grain yield, harvest index up to 26.40 kg P and 40 kg S ha^{-1} (Singh *et al.,* 1999). In the sandy loam soil significant increase in total dry matter was observed when 50 mg P kg^{-1} was applied in combination with 12.5 mg S kg^{-1}. In the sandy soil, application of P and S @ 25 mg kg^{-1} resulted in a significant increase in dry matter yield. Highly significant positive interaction was obtained between P and S in terms of total P uptake at lower rates of S application, higher rates of S resulted in a decreased total P uptake in both the soils. N uptake which is directly linked with protein content in both wheat and soybean improved with medium dose of phosphate, while the medium and high doses of S performed better than low dose for oil content in soybean grain. Application of S and P nutrients together increased grain yield (Hunter, 1987).

The review of the works presented above, thus gives an idea that sulphur and phosphorus had an influence on the growth and yield by soybean and other oil crops. The optimum and adequate level of sulphur and phosphorus application are, therefore, very important for attaining higher growth and yield of soybean in relation to sulphur and phosphorus fertilizer management are still lacking in our country.

Chapter III

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter includes a brief description of the materials and methods that were used in the experiment. This section for convenience has been divided into various sub-heads such as place and 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 P and S on the growth, yield and oil content of soybean.

3.1 Place and Soil of conducting experiments

The research work relating to the study of the role of P and S on the growth, yield and oil content of soybean was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka 1207 during the Rabi season of 2008-2009. 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 2152mm and potential evapotranspiration is 1297mm. The average maximum temperature is 30.34 ^{0}C and average minimum temperature is 21.21^{0}C. The average mean temperature is 25.17 ^{0}C. The experiment was done during the *rabi* season. Temperature during the cropping period was ranged between 12.20 ^{0}C to 29.2 ^{0}C. The humidity varies from 73.52 % to 81.2 5% (Appendix I). The day length was reduced to 10.5 – 11.0 hours only and there was a very little rainfall from the beginning of the experiment to harvesting. The monthly average temperature, humidity, bright sunshine, solar radiation, precipitation and potential evapotranspiration pattern of the site during the experimental work are presented in appendix -I.

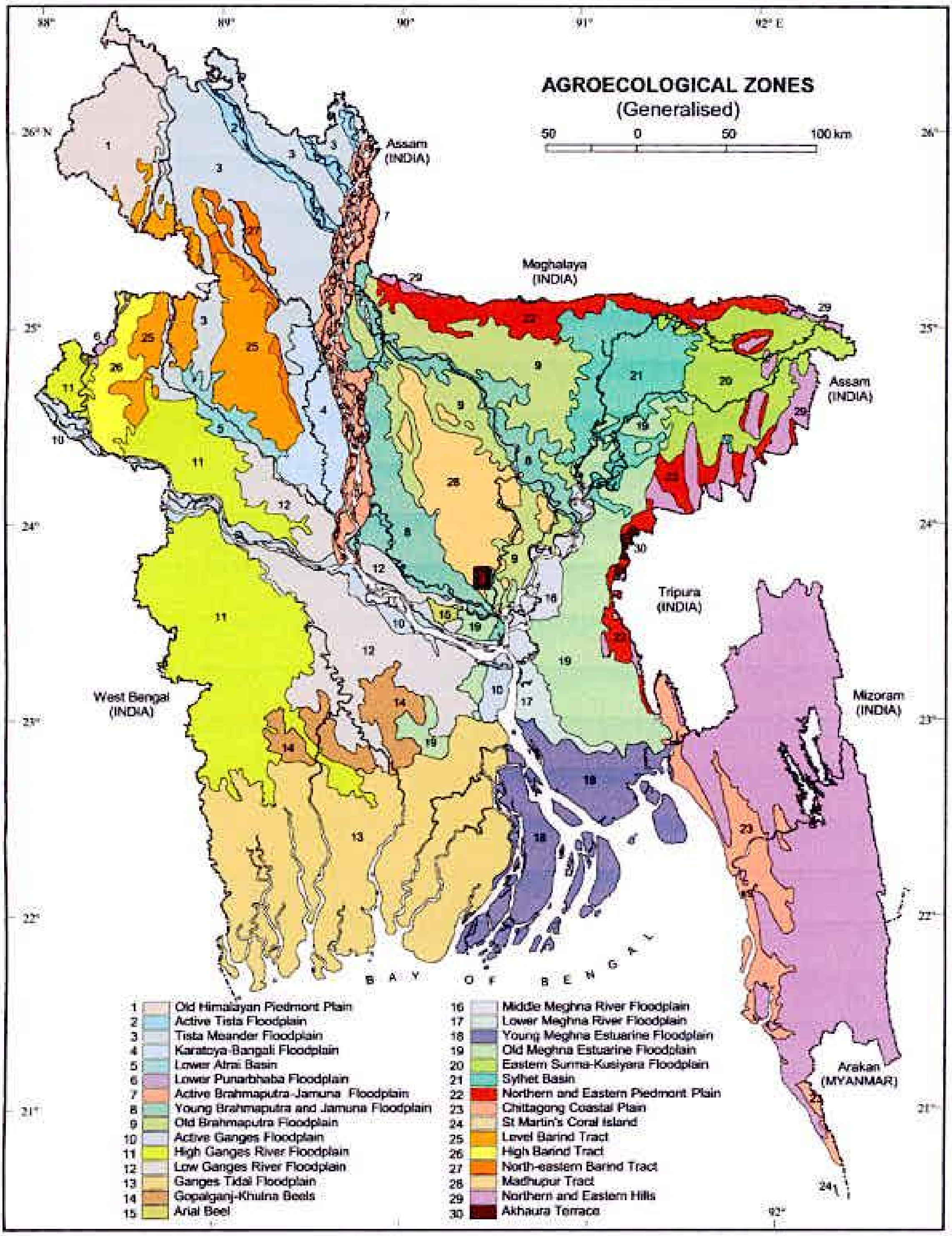

Fig.1. Map showing the experimental site under study

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 oven-dried, ground and passed through 2 mm sieve and analyzed for some important physical and chemical parameters. The morphological characteristics of the experimental field and initial physical and chemical characteristics of the soil are presented in Table 3.1, Table3.2 and Table 3.3.

Table 3.1 Morphological characteristics of the soil of the 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	Tejgoan
Topography	Fairly leveled
Depth of inundation	Above Flood level
Drainage condition	Well Drained
Land type	High Land

Table 3.2 Physical characteristics of the initial soil of the experimental field

% Sand (2-0.02 mm)	31.98
% Silt (0.02-0.002mm)	37.29
% Clay (<0.002mm)	30.73
Textural class	Clay loam

Table 3.3 Chemical characteristics of the initial soil of the experimental field

pH	6.40
Organic matter (%)	0.78
Total N (%)	0.062
Available P (ppm)	10.27
Exchangeable K (meq\100g)	0.114
Available S (ppm)	19.62

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. Healthy, vigorous, plumy and well matured seeds were selected for sowing.

3.5 Preparation of the field

The plot selected for the experiment was opened by power tiller driven rotovator on the 15th December 2008; 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.

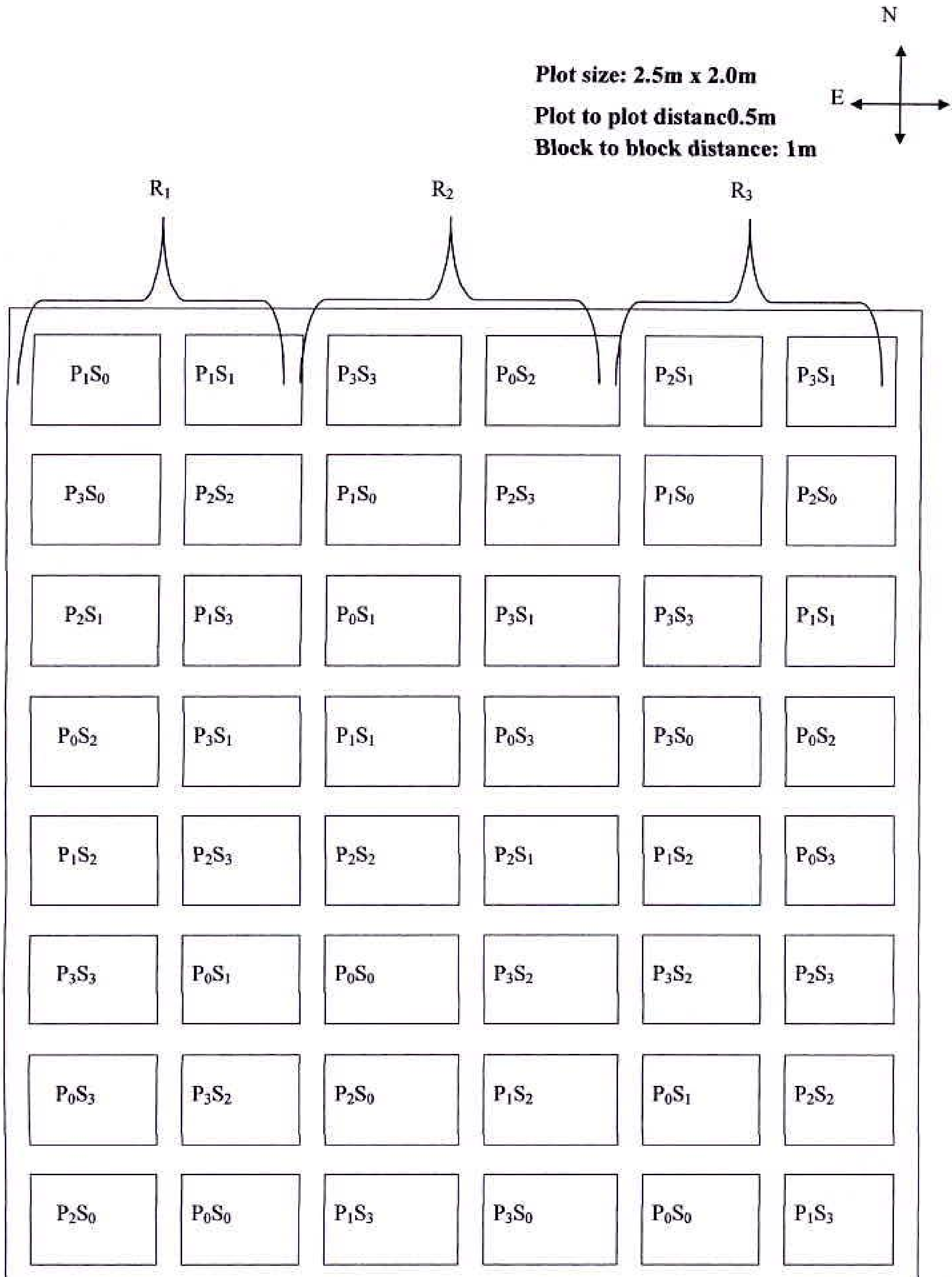

Fig.2: Lay out of the experimental plot

3.7 Treatments

Fertilizer treatments consisted of 4 levels of P (0, 15, 30 and 50 kg P ha^{-1} designated as P_0, P_1, P_2 and P_3, respectively) and 4 levels of S (0, 10, 20 and 40 kg S ha^{-1} designated as S_0, S_1, S_2 and S_3, respectively).There were 16 treatment combinations. The rates of P and S and their treatment combinations are shown below:

A. Rates of Phosphorus (4):

1. $P_0 = 0$ kg P ha^{-1}
2. $P_1 = 15$ kg P ha^{-1}
3. $P_2 = 30$ kg P ha^{-1}
4. $P_3 = 50$ kg P 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. $S_3 = 40$ kg S ha^{-1}

Treatment combinations

1. P_0S_0 =Control (without P and S)
2. P_0S_1 = (0 kg P ha^{-1} + 10 kg S ha^{-1})
3. P_0S_2 = (0 kg P ha^{-1} + 20 kg S ha^{-1})
4. P_0S_3 = (0 kg P ha^{-1} + 40 kg S ha^{-1})
5. P_1S_0 = (15 kg P ha^{-1} + 0 kg S ha^{-1})
6. P_1S_1 = (15 kg P ha^{-1} +10 kg S ha^{-1})
7. P_1S_2 = (15 kg P ha^{-1} + 20 kg S ha^{-1})
8. P_1S_3 = (15 kg P ha^{-1} + 40 kg S ha^{-1})
9. P_2S_0 = (30 kg P ha^{-1} + 0 kg S ha^{-1})
10. P_2S_1 = (30 kg P ha^{-1} + 10 kg S ha^{-1})

11. P_2S_2 = (30 kg P ha^{-1} + 20 kg S ha^{-1})

12. P_2S_3 = (30 kg P ha^{-1} + 40 kg S ha^{-1})

13. P_3S_0 = (50 kg P ha^{-1} + 0 kg S ha^{-1})

14. P_3S_1 = (50 kg P ha^{-1} + 10 kg S ha^{-1})

15. P_3S_2 = (50 kg P ha^{-1} + 20 kg S ha^{-1})

16. P_3S_3 = (50 kg P ha^{-1} + 40 kg S ha^{-1})

3.8 Application of fertilizers

Recommended doses of N, K, Zn and B (30 kg N ha^{-1} from urea, 40 kg K ha^{-1} from MP, 2 kg Zn ha^{-1} from ZnO and 1 kg B $ha^{-1}$from Boric acid, respectively) were applied.

The whole amounts of MP, 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 20-22 days of germination. The required amounts of P (from TSP) and S (from gypsum) were applied at a time as per treatment combination after field lay out of the experiment and were mixed properly through hand spading.

3.9 Seed sowing

Soybean seeds were sown on the 27th December 2008 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 22 days of sowing, on January 18, 2009. 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 07, 2009 at eleven days after sowing (DAS) through irrigation channel. Second irrigation was given in the field on February 10, 2009 at 45 days after sowing (DAS) before flowering. The third irrigation was given at the stage of pod formation (70 DAS) on March 07, 2009.

3.12 Pest Management

The crop was infested with cutworm at the seedling stage and application of Dursban-25EC @ 2.5ml/liter was done twice on January 14 and 22, 2009. 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 14th April 2009. 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 25th April 2009. The samples were oven -dried, ground and sieved through a 2 mm (10 mesh) sieve and kept for analysis.

3.14.2 Plant sample

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

3.15 Collection of data

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

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) Stover yield (t ha^{-1})
9) Biological yield
10) Protein content in seed
11) Oil content in seed
12) N, P, K, and S contents in plant sample
13) Soil pH, organic C, available N, P, K and S contents in post harvest soil

3.15.1 Plant height

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

3.15.2 Number of leaves plant^{-1}

Numbers of leaves were counted at the maximum vegetative stage. 10 plants were selected randomly from each plot and number of leaves were counted andaveraged.

3.15.3 Number of primary branches plant^{-1}

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

3.15.4 Number of pods plant^{-1}

Pods were counted at the ripening stage. 10 plants were selected randomly from each plot. Number of pods were counted and averaged.

3.15.5 Number of seeds plant^{-1}

It was done after harvesting. 10 plants were selected randomly from each plot. At first, number of seeds plant^{-1} were counted and averaged. Then it was multiplied with number of pods plant^{-1} and averaged.

3.15.6 Thousand seed weight

Thousand seed of soybean were counted randomly and then weighed 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 Stover yield

Stover 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}.

3.15.9 Biological yield

Grain yield and stover yield are altogether considered as biological yield. The biological yield is calculated by following formula.

Biological yield= Grain yield + Stover yield.

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.

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 30% H_2O_2, conc. H_2SO_4 and a catalyst mixture (K_2SO_4: $CuSO_4.5H_2O$: Selenium powder in the ratio 100 : 10 : 1, respectively) for the determination of total nitrogen by Micro-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).

3.16.2 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 30% H_2O_2 conc. H_2SO_4 and catalyst mixture (K_2SO_4: $CuSO_4.5H_2O$: Selenium powder in the ratio 100: 10 : 1, respectively). Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate absorbed in H_3BO_3 with 0.01N H_2SO_4 (Jackson, 1973).

3.16.2. d) Available Phosphorous

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

3.16.2. e) Available Potassium

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

3.16.2. f) Available Sulphur

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

3.16.2. g) Soil pH

Soil pH was determined by pH meter.

3.17 Methods for seed analysis

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

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

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

3.18 Statistical analysis

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

Chapter IV

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

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

4. Yield parameters of soybean

4.1 Plant height

4.1.1 Effect of phosphorus on the plant height of soybean

The plant height of soybean varied significantly with different phosphorus levels (table.4.1). Significant variation was observed on the plant height of soybean when the field was fertilized with different doses of phosphorus. Among the different doses of phosphorus, P_3 (50 kg P ha^{-1}) showed the highest plant height (68.50 cm) and it was closely followed by P_2 (30 kg P ha^{-1}) treatment showing 66.66 cm plant height. On the other hand, the lowest plant height (64.06 cm) was observed in the P_0 treatment where no phosphorus was applied. Plant height increased with increasing levels of phosphorus up to maximum level of P application. The increased plant height may be due to favorable effects of phosphorus on the vegetative growth of soybean plant. The results are similar to those of Bothe *et al.* (2000) who reported that the application of phosphorus @ 75 kg ha^{-1} enhanced the plant height at highest value. Maurya and Rathi (2000) also found the positive effect of P on the plant height of soybean.

4.1.2 Effect of sulphur on the plant height of soybean

Soybean plants showed significant variation in respect of plant height when different doses of sulphur fertilizer were applied (Table 4.2). Among the different fertilizer doses, S_3 (40 kg S ha^{-1}) showed the highest plant height (68.21 cm) which was statistically similar with S_2 (20 kg S ha^{-1}) treatment. Plant height increased with increasing levels of sulphur up to maximum level of S application. The increased plant height may be due to favorable effects of sulphur on the vegetative growth of soybean plant. These findings are similar to those of Ghosh *et al.* (1997) who reported that sulphur @ 40kg ha^{-1} enhanced the plant height. Similar results were also found by Chaubey *et at.* (2000) in groundnut and Dubey *et al.* (1997) in linseed. Shortest plant was obtained from control condition. The result is similar to Tabatabai (1986) who reported that lack of sulphur reduces plant height. The lowest height was found at control condition. It was further noticed that plant height of soybean increased as the level of S was increased.

Table 4.1: Effect of P on the vegetative growth of soybean

Treatments	Plant height (cm)	Number of primary branches $plant^{-1}$	Number of leaves $plant^{-1}$
P_0	64.06 c	2.46 c	10.30 b
P_1	64.46 c	2.96 b	10.82 a b
P_2	66.66 b	3.53 a	11.34 a
P_3	68.50 a	3.59 a	11.38 a
CV (%)	2.04	7.32	8.37

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 phosphorus and sulphur on the plant height of soybean

Crop responses to sulphur and phosphorus interaction for plant height has been presented in Table 4.3. It can be observed that the interaction of sulphur and phosphorus levels show significant effect on plant height .The lowest plant height (60.87 cm) was observed in the control treatment combination (No phosphorus and No sulphur). On the other hand, the highest plant height (70.35 cm) was recorded with P_3S_3 (50 kg K ha^{-1} + 40 kg S ha^{-1}) treatment combination which was statistically identical to P_3S_2 (30 kg K ha^{-1} + 20 kg S ha^{-1}), P_3S_1 (50 kg K ha^{-1} + 10 kg S ha^{-1}), P_2S_3 (30 kg K ha^{-1} + 40 kg S ha^{-1}) treatment combination and followed by P_2S_2 (30 kg K ha^{-1} + 20 kg S ha^{-1}) treatment combination. Tomar et al (2004) also found the positive interaction effect of P and S on the plant height of soybean. The highest plant height may be due to the positive effects of phosphorus and sulphur on the vegetative growth and accumulation of growth materials. Further it could be seen (Table-4.3) that the interaction effect of increased levels of phosphorus and sulphur increased plant height also.

Table 4.2: Effect of S on the vegetative growth of soybean

Treatments	Plant height (cm)	Number of primary branches $plant^{-1}$	Number of leaves $plant^{-1}$
S_0	62.82 c	2.625 c	9.95 b
S_1	65.46 b	3.075 b	10.71 ab
S_2	67.20a	3.492 a	11.55 a
S_3	68.21a	3.362 a	11.63 a
CV (%)	2.04	7.32	8.37

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

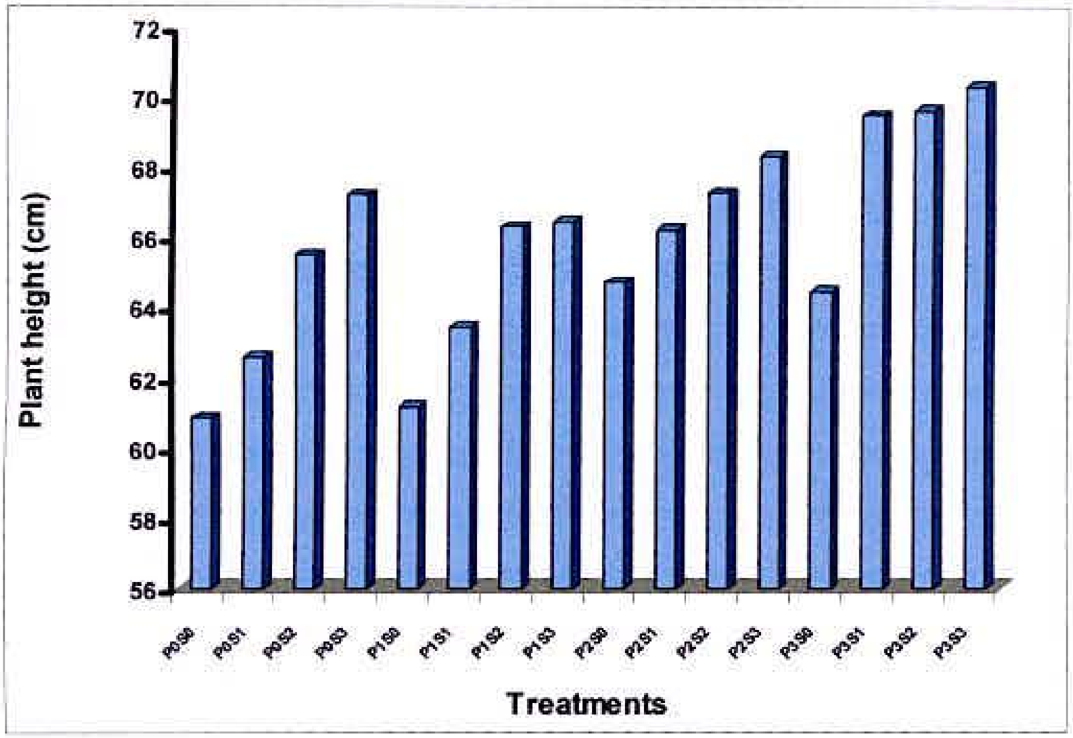

Fig 3: Combined effect of P and S on the plant height of soybean

4.2 Number of primary branches plant^{-1}

4.2.1 Effect of phosphorus on the number of primary branches plant^{-1} of soybean

Phosphorus had a significant influence on the number of primary branches plant^{-1} of soybean when different doses of phosphorus were applied (Table 4.1). The highest number of primary branches plant^{-1} (3.59) was recorded in P_3 (50 kg P ha^{-1}) which was statistically similar with the P_2 (30 kg P ha^{-1}) treatment. The lowest number of primary branches plant^{-1} (2.46) was recorded in the P_0 treatment where no phosphorus was applied. The increased number of primary branches plant^{-1} may be due to favorable effects of phosphorus on the vegetative growth and accumulation of growth materials that helped proper growth and development of the soybean plant.

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

From Table 4.2 it could be seen that different doses of sulphur fertilizer showed significant variations in respect of number of primary branches plant^{-1}. Among the different doses of sulphur, S_2 (20 kg S ha^{-1}) showed the highest number of primary branches plant^{-1} (3.49) which was statistically similar with the S_3 (40 kg S ha^{-1}) treatment. On the contrary, the lowest number of primary branches plant^{-1} (2.62) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The increased number of primary branches plant^{-1} may be due to positive effects of sulphur on the vegetative growth and accumulation of growth promoting substances 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^{-1}. Dubey et al. (1997) reported that S increased the number of primary branches per plant of linseed up to 40 kg S ha^{-1}. Similar findings were obtained by Ghosh et al. (1997).

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

The combined effect of different doses of P and S fertilizer on the number of primary branches plant^{-1} of soybean was significant (Table 4.3 and Fig.4). The highest number of primary branches plant^{-1} (4.167) was recorded with the treatment combination of P_3S_2 (50 kg P ha^{-1} + 20 kg S ha^{-1}) which was followed by P_2S_3 (30 kg P ha^{-1} + 40 kg S ha^{-1}) and P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) treatment combinations. On the other hand, the lowest number of primary branches plant^{-1} (2.0) was recorded in the P_0S_0 treatment (control) combination. The highest number of primary branches plant^{-1} may be due to the fact that, the combined effect of both phosphorus and sulphur played positive effect on the growth and development of soybean plant.

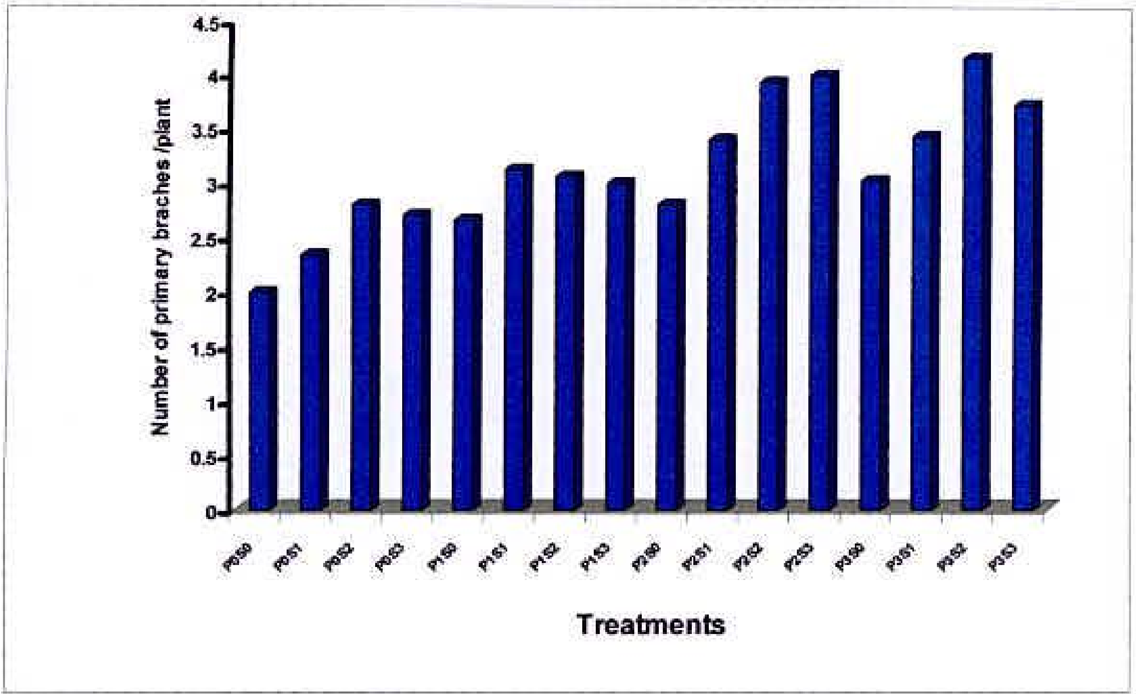

Fig.4. Combined effect of P and S on the number of primary branch plant^{-1}

4.3 Number of leaves plant^{-1}

4.3.1 Effect of phosphorus on the number of leaves plant^{-1} of soybean

Significant variation was observed in the number of leaves plant^{-1} of soybean when different doses of phosphorus were applied (Table 4.1). The highest number of leaves plant^{-1} (11.38) was recorded in P_3 (50 kg P ha^{-1}) treatment which was statistically similar with P_2 (30 kg P ha^{-1}) treatment. The lowest number of leaves plant^{-1} (10.30) was recorded in the P_0 treatment where no phosphorus was applied. The increased number of leaves plant^{-1} may be due to favorable effects of phosphorus on the vegetative growth and accumulation of growth materials that helped proper growth and development of the soybean plant.

4.3.2 Effect of sulphur on the number of leaves plant^{-1} 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_3 (40 kg S ha^{-1}) showed the highest number of leaves plant^{-1} (11.63) which was statistically similar with S_2 (20 kg S ha^{-1}). On the contrary, the lowest number of leaves plant^{-1} (9.950) 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 growth promoting 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 phosphorus and sulphur on the number of leaves plant^{-1} of soybean

The combined effect of different doses of P and S fertilizers on the number of leaves plant^{-1} of soybean was significant (Table 4.3 and Fig.5). The highest number of leaves plant^{-1} (12.53) was recorded with the treatment combination of P_3S_3 (50 kg P ha^{-1} + 40 kg S ha^{-1}). On the other hand, the lowest number of leaves plant^{-1} (9.133) was recorded in the P_0S_0 treatment (control) combination. The highest number of leaves plant^{-1} may be due to the fact that, the combined effect of both phosphorus and sulphur played positive effect on the growth and development of soybean plant.

Table 4.3: Interaction effect of P and S on the vegetative growth of soybean

Treatments	Plant height (cm)	Number of primary branches plant^{-1}	Number of leaves plant^{-1}
P_0S_0	60.87 i	2.00i	9.13 e
P_0S_1	62.60 g-i	2.33hi	9.33de
P_0S_2	65.53 d-f	2.80fg	11.7ab
P_0S_3	67.25 b-d	2.71f-h	11.0a-d
P_1S_0	61.18hi	2.66gh	9.53c-e
P_1S_1	63.46f-h	3.13d-f	10.6b-e
P_1S_2	66.34c-e	3.06d-g	11.7ab
P_1S_3	66.46 c-e	3.00e-g	11.40ab
P_2S_0	64.74d-g	2.80fg	10.87a-d
P_2S_1	66.25c-e	3.40c-e	11.67ab
P_2S_2	67.29b-d	3.93ab	11.27a-c
P_2S_3	68.36 a-c	4.00ab	11.57ab
P_3S_0	64.50e-g	3.03d-g	10.27b-e
P_3S_1	69.52ab	3.43cd	11.23a-c
P_3S_2	69.65ab	4.16a	11.47ab
P_3S_3	70.35a	3.73bc	12.53a
CV (%)	2.04	7.32	8.37

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

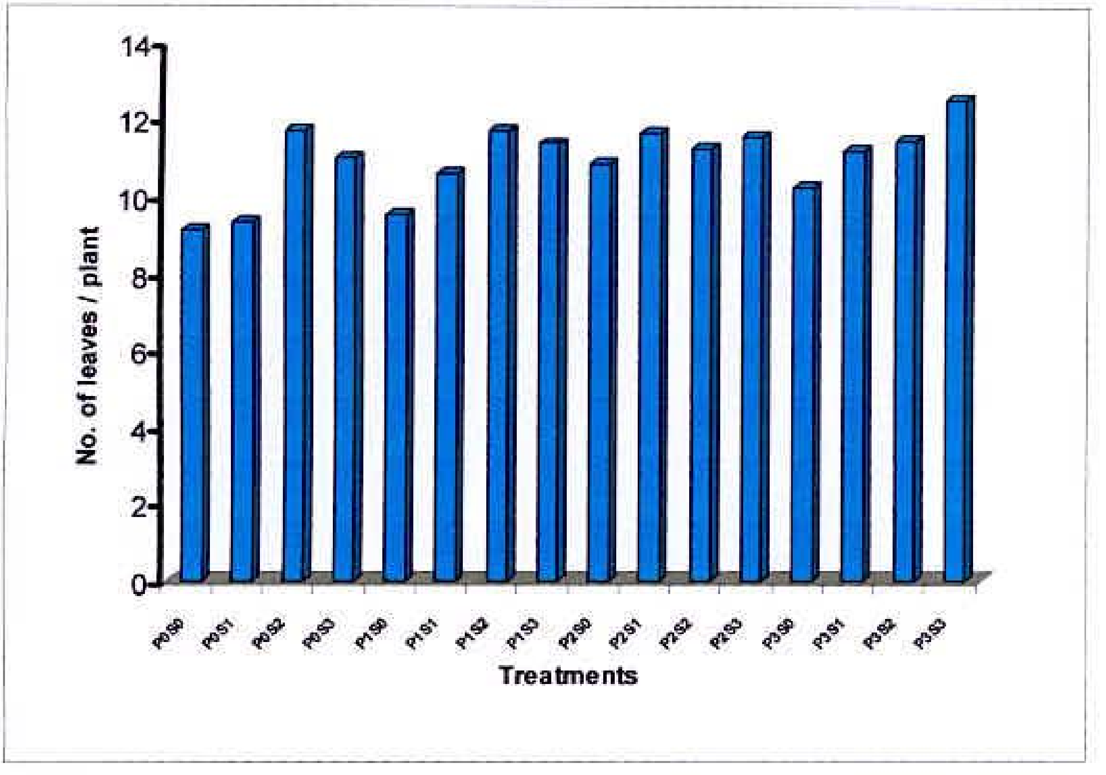

Fig 5: Combined effect of P and S on the number of leaves plant^{-1}

4.4 Number of pods plant^{-1}

4.4.1 Effect of phosphorus on the number of pods plant^{-1} of soybean

Significant variation was found in the number of pods plant^{-1} of soybean when different doses of phosphorus were applied (Table 4.4). The highest number of pods plant^{-1} (27.73) was recorded in P_2 (30 kg P ha^{-1}) treatment. The lowest number of pods plant^{-1} (14.57) was recorded in the P_0 treatment where no phosphorus was applied. These findings are similar to those of Reddy and Gajendragiri (1989) who reported that phosphorus @ 20 kg P ha^{-1} increased the pod yield of soybean. Similar results were also found by Jana *et at.* (1990) and Singh and Bajpai (1990) in soybean. The increased number of pods plant^{-1} may be due to favorable effects of phosphorus on the vegetative growth and accumulation of materials that helped proper growth and development of the soybean pod.

4.4.2 Effect of sulphur on the number of pods plant^{-1} of soybean

Different doses of sulphur fertilizer showed significant variations in respect of number of pods plant^{-1} (Table 4.5). Among the different doses of fertilizers, S_3 (40 kg S ha^{-1}) showed the highest number of pods plant^{-1} (25.38) which was statistically similar with S_2 (20 kg S ha^{-1}). On the contrary, the lowest number of pods plant^{-1} (19.21) 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 growth 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^{-1} in the presence of *Bradyrhizobium* inoculation. Arunageeta *et al.* (2006) observed that the highest number of pods plant^{-1} was obtained with the application of 30 kg S ha^{-1}.

4.4.3 Interaction effect of phosphorus and sulphur on the of number of pods plant^{-1} of soybean

The combined effect of different doses of P and S fertilizers on the number of pods plant^{-1} of soybean was significant (Table 4.6 and Fig.6). The highest number of pods plant^{-1} (30.73) was recorded with the treatment combination of P_2S_3 (30 kg P ha^{-1} + 40 kg S ha^{-1}). On the other hand, the lowest number of pods plant^{-1} (13.00) was recorded in the P_0S_0 treatment (control) combination. Majumdar *et. al.* (2001) found that combined application of P and S @ 60 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1} increased the number of pods plant^{-1}.The highest number of pods plant^{-1} may be due to the fact that, the combined effect of both phosphorus and sulphur had positive effect on the vegetative growth and accumulation of growth promoting materials that helped proper growth and development of the soybean pod.

Table4.4: Effect of P on the yield and yield attributing characteristics of soybean

Treatments	Number of pods plant^{-1}	Number of seeds plant^{-1}	1000 seed weight(g)	Grain yield (ton ha^{-1})	Stover yield (ton ha^{-1})	Biological yield(ton ha^{-1})
P_0	14.57 d	54.20c	88.62c	1.51c	2.47c	4.00c
P_1	22.42c	68.27b	90.73b	1.85b	2.80b	4.63b
P_2	27.73a	80.21a	93.57a	2.04a	2.89a	4.96a
P_3	26.82b	78.28a	92.71a	2.03a	2.93a	4.92a
CV (%)	4.14	9.11	1.31	4.73	3.25	2.56

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

4.5 Number of seeds plant^{-1}

4.5.1 Effect of phosphorus on the number of seeds plant^{-1} of soybean

Significant variation was observed in the number of seeds plant^{-1} of soybean when different doses of phosphorus were applied (Table 4.4). The highest number of seeds plant^{-1} (80.21) was recorded in P_2 (30 kg P ha^{-1}) treatment which was statistically similar with P_3 (50 kg P ha^{-1}) treatment. The lowest number of seeds plant^{-1} (54.20) was recorded in the P_0 treatment where no phosphorus was applied. The number of seeds plant^{-1} increased with increasing levels of phosphorus up to certain level. The increased number of seeds plant^{-1} may be due to the favorable effects of phosphorus on the vegetative growth and accumulation of growth materials that helped in obtaining the highest number of seeds plant^{-1} of soybean. The result confirms with the findings of Jana *et al.* (1990).

4.5.2 Effect of sulphur on the number of seeds plant^{-1} of soybean

Different doses of sulphur fertilizer showed significant variations in respect of number of seeds plant^{-1} (Table 4.5). Among the different doses of fertilizers, S_3 (40 kg S ha^{-1}) showed the highest number of seeds plant^{-1} (75.40) which was statistically similar with S_2 (20 kg S ha^{-1}) and S_1 (10 kg S ha^{-1}) treatments. On the contrary, the lowest number of seeds plant^{-1} (62.82) 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 growth promoting materials that helped in obtaining the highest number of seeds plant^{-1} of soybean. The present studies are in accordance with the findings of Dubey *et al.* (1997) who reported that seeds capsule^{-1} of linseed increased significantly due to increased levels of sulphur. Saran and Giri (1990) also found similar results with the application of 60 kg S ha^{-1}.

4.5.3 Interaction effect of phosphorus and sulphur on the of number of seeds plant^{-1} of soybean

The combined effect of different doses of P and S fertilizers on the number of seeds plant^{-1} of soybean was significant (Table 4.6 and Fig.7). The highest number of seeds plant^{-1} (84.94) was recorded with the treatment combination of P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) which was statistically similar with P_2S_3 (30 kg P ha^{-1}+ 40 kg S ha^{-1}) and P_3S_2 (50 kg P ha^{-1} + 20 kg S ha^{-1}) treatment combinations. On the other hand, the lowest number of seeds plant^{-1} (50.29) was recorded in the P_0S_0 treatment (control) combination. The present studies are in accordance with the findings of Tomar *et al.* (2004) and Majumdar *et al.* (2001) who reported that seeds plant^{-1} of soybean increased significantly due to combined application of increased levels of phosphorus and sulphur. Optimum fertilizer doses increased the vegetative growth and development of soybean that lead to the formation of the highest number of seeds plant^{-1}.

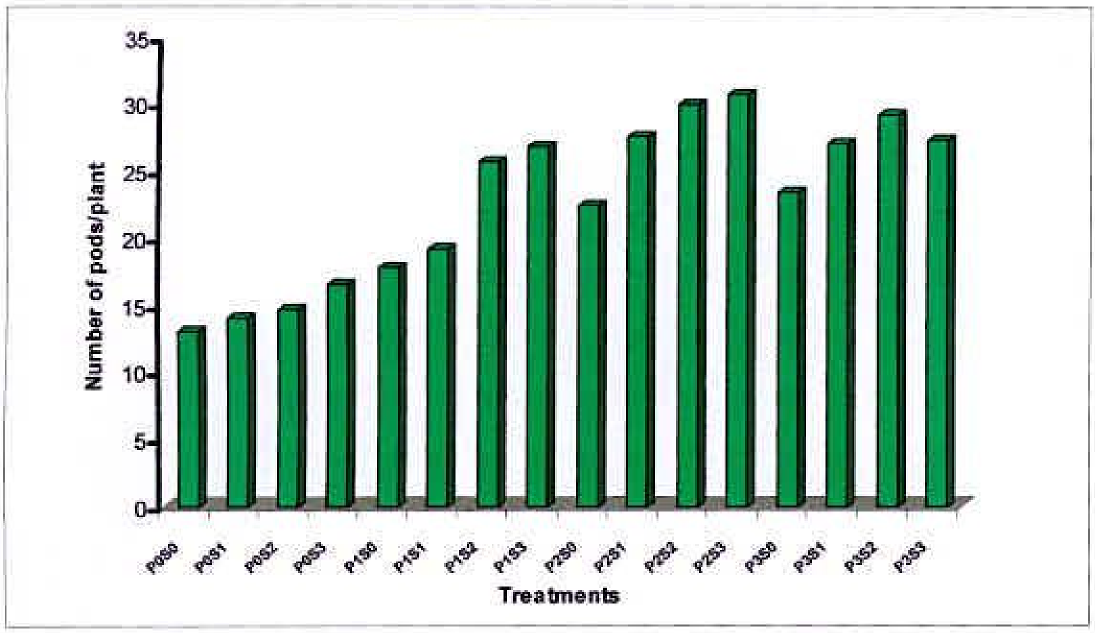

Fig.6. Combined effect of P and S on the number of pods plant^{-1} of soybean

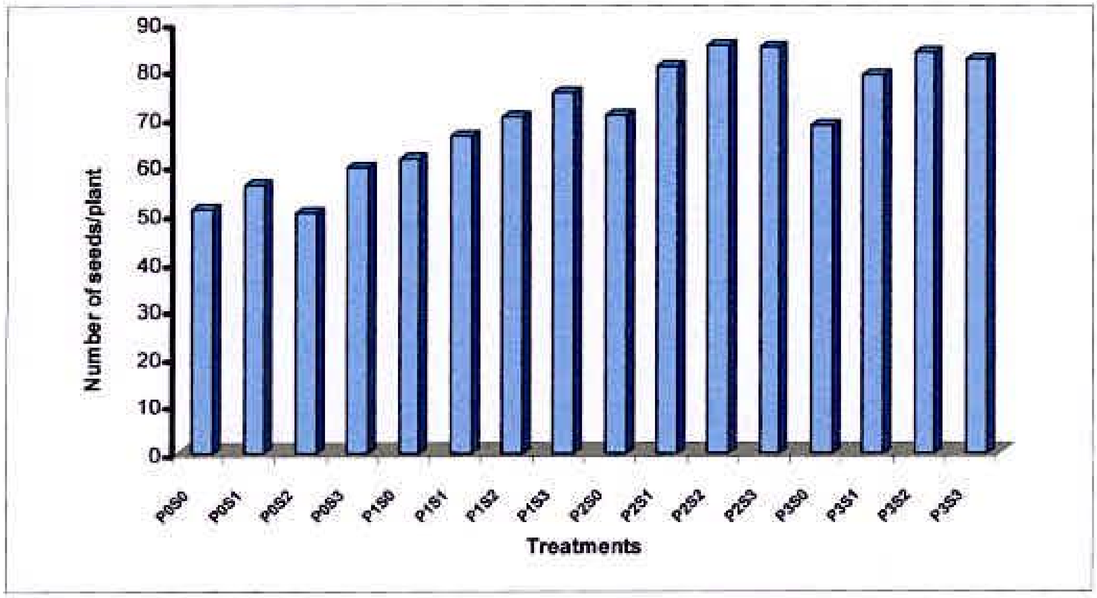

Fig.7. Combined effect of P and S on the number of seeds plant^{-1} of soybean

4.6 Weight of 1000 seed (g)

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

Significant variation was observed on the weight of 1000 seed of soybean when different doses of phosphorus were applied (Table 4.4). The highest weight of 1000 seed (93.57 g) was recorded in P_2 (30 kg P ha^{-1}) treatment which was statistically similar with P_3 (50 kg P ha^{-1}). The lowest weight of 1000 seed (88.62 g) was recorded in the P_0 treatment where no phosphorus was applied. The increased grain weight may be due to the favorable effects of phosphorus on the vegetative growth and accumulation of plant growth materials that helped proper growth and development of the soybean grain. The result confirms with the findings of Reddy and Gajendragiri (1989).

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 of 1000 seed (Table 4.5). Among the different doses of S fertilizer, S_3 (40 kg S ha^{-1}) showed the highest weight of 1000 seed (92.78 g) which is statistically similar with S_2 (20 kg S ha^{-1}). On the contrary, the lowest weight of 1000 seed (89.10 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 growth promoting materials that helped proper growth and development of the soybean grain. These results are in agreement with the findings of Hemantarajan and Trivedi (1997), Agrawal and Mishra (1994) who reported that S application increased 1000-seed weight of soybean. Saran and Giri (1990) also found similar results with the application of 60 kg S ha^{-1}.

Table 4.5: Effect of S on the yield and yield attributing characteristics of soybean

Treatments	Number of pods plant^{-1}	Number of seeds plant^{-1}	1000-seed weight(g)	Grain yield (ton ha^{-1})	Stover yield (ton ha^{-1})	Biological yield(ton ha^{-1})
S_0	19.21c	62.82b	89.10c	1.57c	2.51c	4.11c
S_1	22.02b	70.43a	91.13b	1.74b	2.74b	4.49b
S_2	24.92a	72.32a	92.62a	2.06a	2.94a	4.98a
S_3	25.38a	75.40a	92.78a	2.06a	2.91a	4.94a
CV (%)	4.14	9.11	1.31	4.73	3.25	2.56

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

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

The combined effect of different doses of P and S fertilizers on the weight of 1000 seed of soybean was significant (Table 4.6). The highest weight of 1000 seed (94.61 g) was recorded with the treatment combination of P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}). On the other hand, the lowest weight of 1000 seed (86.98 g) was recorded in the P_0S_0 treatment (control treatment). The weight of 1000 seed increased with increasing level of phosphorus and sulphur up to optimum level due to the favorable effects of fertilizer on the yield attributes.

4.7 Grain yield of soybean (t ha^{-1})

4.7.1 Effect of phosphorus on the grain yield of soybean

Significant variation was observed on the grain yield of soybean when different doses of phosphorus were applied (Table 4.4). The highest grain yield of soybean

(2.046 t ha^{-1}) was recorded in P_2 (30 kg P ha^{-1}) treatment which was statistically similar with P_3 (50 kg P ha^{-1}) treatment. The lowest grain yield (1.518 t ha^{-1}) was recorded in the P_0 treatment where no phosphorus was applied. These results were similar with the findings of Maurya and Rathi (2000) who reported that grain yield was maximum with the application of 60 kg P ha^{-1} .The increased grain yield may be due to the positive effects of phosphorus on the vegetative growth and accumulation of plant growth materials that helped proper growth and development of the soybean grain.

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 of soybean (Table 4.5). Among the different doses of S fertilizer, S_2 (20 kg S ha^{-1}) showed the highest grain yield of soybean (2.068 t ha^{-1}) which was statistically similar with S_3 (40 kg S ha^{-1}) treatment. On the contrary, the lowest weight grain yield of soybean (1.578 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 favorable effects of sulphur on the vegetative growth and accumulation of growth 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^{-1} in the presence of *Bradyrhizobium* inoculation. Sangale *et al.* (2004) observed that application of S at 20 kg ha^{-1} gave highest seed yield. Mohanti *et al.* (2004) found similar results with the application of 30 kg S ha^{-1}. Tomar *et al.* (2000) reported that the highest seed yield (2257 kg ha^{-1}) was recorded with the application of 50 kg S ha^{-1} regardless of sources.

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

The combined effect of different doses of P and S fertilizers on the grain yield of soybean was significant (Table 4.6 and Fig.8). The highest grain yield of soybean (2.297 t ha^{-1}) was recorded with the treatment combination of P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) which were statistically similar with P_3S_2 (50 kg P ha^{-1}+20 kg S ha^{-1}). On the other hand, the lowest grain yield of soybean (1.327 t ha^{-1}) was recorded in the P_0S_0 treatment (control) combination. The present studies are in accordance with the findings of Tomar *et al.* (2004) and Majumdar *et al.* (2001) who reported that grain yield of soybean increased significantly due to combined application of increased levels of phosphorus and sulphur. Grain yield increased with increasing level of phosphorus and sulphur up to optimum level due to the positive effect of fertilizers on the yield attributes.

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

4.8.1 Effect of phosphorus on the stover yield of soybean

Significant variation was observed on the stover yield of soybean when different doses of phosphorus were applied (Table 4.4). The highest stover yield of soybean (2.94 t ha^{-1}) was recorded in P_3 (50 kg P ha^{-1}), which was statistically similar with P_2 (30 kg P ha^{-1}) treatment. The lowest stover yield (2.47 t ha^{-1}) was recorded in the P_0 treatment where no phosphorus was applied. The findings for these characters agree with the results obtained by Khandkar *et al.* (1985) and Sacchindanand et al (1980) who observed that straw yields of soybean increased with the application of P @ 30 kg P_2O_5 ha^{-1}.

4.8.2 Effect of sulphur on the stover yield of soybean

Different doses of sulphur fertilizer showed significant variations in respect of stover yield of soybean (Table 4.5). Among the different doses of S fertilizer, S_2 (20 kg S ha^{-1}) showed the highest stover yield of soybean (2.942 t ha^{-1}). On the contrary, the lowest weight of stover yield of soybean (2.515 t ha^{-1}) was recorded in the S_0 treatment where no sulphur fertilizer was applied. The findings for these characters agree with the results obtained by Tomar *et al.* (1995) who observed that straw yields of mustard increased with increased S rates.

Table4.6: Interaction effect of P and S on the yield and yield attributing characteristics of soybean

Treatments	Number of pods $plant^{-1}$	Number of seeds $plant^{-1}$	1000 seed weight (g)	Grain yield (ton/ha)	Stover yield (ton/ha)	Biological yield(ton/ha)
P_0S_0	13 i	50.29 g	86.98 f	1.32 f	1.95 g	3.28h
P_0S_1	14.07 hi	55.88fg	87.53f	1.38 f	2.45f	3.87g
P_0S_2	14.67 h	50.99g	89.43 e	1.62 e	2.82c-e	4.45ef
P_0S_3	16.57g	59.65 e-g	90.54 de	1.73 de	2.67e	4.40f
P_1S_0	17.87fg	61.51 e-g	87.37 f	1.44 f	2.50f	3.94g
P_1S_1	19.23 f	66.12d-f	90.39 de	1.84 d	2.82c-e	4.67cd
P_1S_2	25.77 d	70.34b-e	92.63a-c	2.08bc	2.87b-d	4.95b
P_1S_3	26.83cd	75.13a-d	92.54 bc	2.06c	3.01 ab	4.97b
P_2S_0	22.43 e	70.49b-e	91.76cd	1.77de	2.86b-d	4.71cd
P_2S_1	27.67bc	80.76 ab	93.43a-c	1.88d	2.74 de	4.62c-e
P_2S_2	30.07 a	84.94 a	94.61 a	2.29a	3.01 ab	5.30a
P_2S_3	30.73a	84.65 a	94.46 ab	2.22ab	2.98a-c	5.20a
P_3S_0	23.53e	68.29c-e	90.28 de	1.76de	2.74de	4.50d-f
P_3S_1	27.13cd	78.95 a-c	93.18a-c	1.88d	2.94a-c	4.79bc
P_3S_2	29.20ab	83.69 a	93.82 ab	2.27a	3.06 a	5.23a
P_3S_3	27.40cd	82.18 ab	93.58a-c	2.22ab	2.99ab	5.18a
CV (%)	4.14	9.11	1.31	4.73	3.25	2.56

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

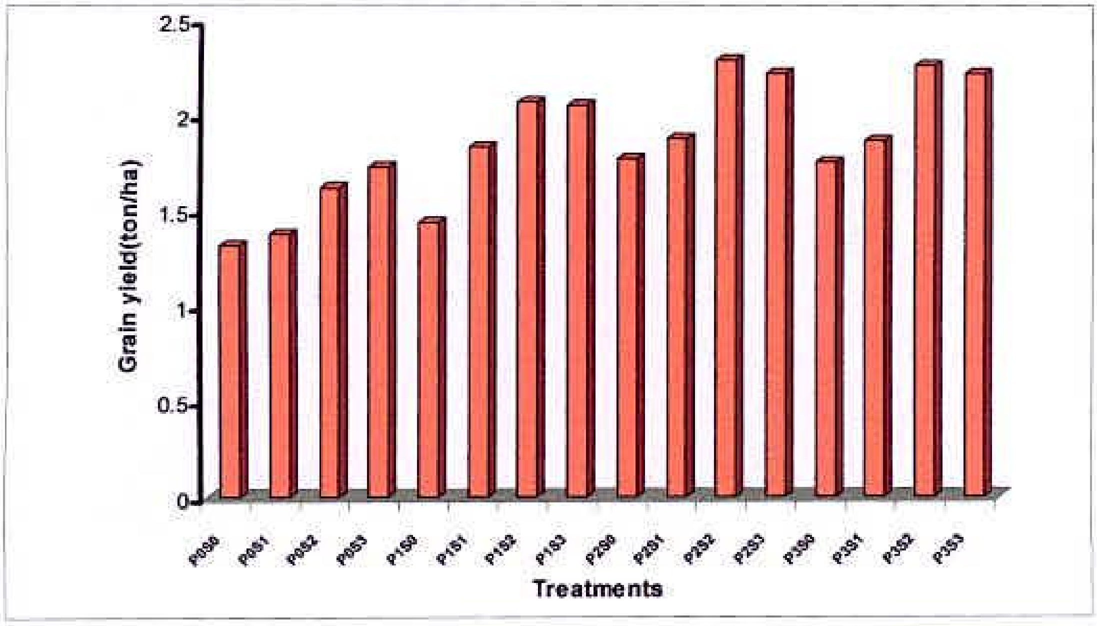

Fig.8. Combined effect of P and S on the grain yield (t ha^{-1}) of soybean

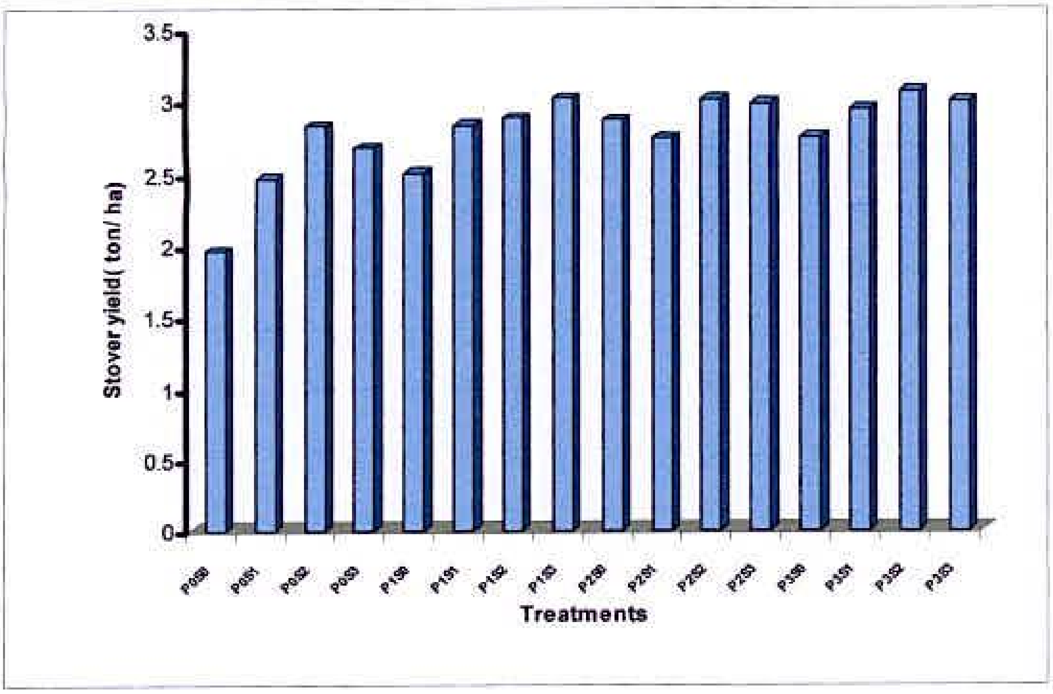

Fig 9: Interaction effect of P and S on the stover yield (t ha^{-1}) of soybean

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

The combined effect of different doses of P and S fertilizers on the stover yield of soybean was significant (Table 4.6). The highest stover yield of soybean (3.1 t ha^{-1}) was recorded with the treatment combination of P_3S_2 (50 kg P ha^{-1} + 20 kg S ha^{-1}) .On the other hand, the lowest stover yield of soybean (1.9533 t ha^{-1}) was recorded in the P_0S_0 treatment (control) combination. Tomar *et al.* (2004) and Majumdar *et al.* (2001) reported that straw yield of soybean increased significantly due to combined application of increased levels of phosphorus and sulphur.

4.9. Biological yield of soybean (t ha^{-1})

4.9.1. Effect of phosphorus on the biological yield of soybean

Significant variation was observed on the biological yield of soybean when different doses of phosphorus were applied (Table 4.4). The highest biological yield of soybean (4.964 t ha^{-1}) was recorded in P_2 (30 kg P ha^{-1}), which was statistically similar with P_3 (50 kg P ha^{-1}) treatment. The lowest biological yield (4.003 t ha^{-1}) was recorded in the P_0 treatment where no phosphorus was applied. The increase in biological yield might be due to higher grain yield in relation to stover yield by phosphorus application.

4.9.2 Effect of sulphur on the biological yield of soybean

Different doses of sulphur fertilizer showed significant variations in respect of biological yield of soybean (Table 4.5). Among the different doses of S fertilizer, S_2 (20 kg S ha^{-1}) showed the highest biological yield of soybean (4.986 t ha^{-1}) which was statistically similar with S_3 (40 kg S ha^{-1}) treatment. On the contrary, the lowest weight in biological yield of soybean (3.112 t ha^{-1}) was recorded in the S_0 treatment where no sulphur fertilizer was applied. From the result it can be concluded that sulphur increased the biological yield which might be due to the cumulative favorable effect of the grain and stover yield.

4.9.3 Interaction effect of phosphorus and sulphur fertilizers on the biological yield of soybean

The combined effect of different doses of P and S fertilizers on the biological yield of soybean was significant (Table 4.6). The highest biological yield of soybean (5.307 t ha^{-1}) was recorded with the treatment combination of P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) .On the other hand, the lowest biological yield of soybean (3.280 t ha^{-1}) was recorded in the P_0S_0 treatment (control).

4.10. Total nitrogen content in soybean plant

4.10.1 Effect of P on nitrogen content in soybean plant

Application of P showed significant variation on the nitrogen concentration in soybean plant (Table 4.7). The highest nitrogen concentration in soybean plant (0.9973%) was recorded in P_2 (30 kg P ha^{-1}) treatment. On the other hand, the lowest nitrogen concentration in soybean plant (0.6143%) was recorded in the P_0 treatment where no P was applied. These results were found due to the positive effect of phosphorus on the atmospheric N-fixation of soybean plant and become available for plant uptake.

4.10.2 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 4.8). The highest nitrogen concentration among the treatments of sulphur (1.005%) was observed in S_2 (20 kg S ha^{-1}). On the other hand, the lowest nitrogen concentration in soybean plant (0.4095%) was observed in the S_0 (control condition) treatment. These results were found due to the positive effect of sulphur on the N-fixing bacteria that fix atmospheric N and become suitable for plant uptake.

4.10.3 Interaction effect of P and S on nitrogen content in soybean plant

Significant effect of combined application of different doses of P and S fertilizers on the nitrogen concentration was observed in the soybean plant (Table 4.9). The highest concentration (1.294%) of nitrogen in the soybean plant was recorded with P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) which were statistically similar with P_2S_1 (30 kg P ha^{-1} + 10 kg S ha^{-1}). On the other hand, the lowest nitrogen concentration in soybean plant (0.318%) was observed in the P_0S_0 treatment. These results were found due to the positive effect of both phosphorus and sulphur on atmospheric N-fixation and increased plant uptake.

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

Treatments	Total N (%)	Total P (%)	Total K (%)	Total S (%)
P_0	0.61d	0.53d	2.02c	0.41d
P_1	0.75c	0.79c	2.11b	0.42c
P_2	0.99a	1.13b	2.12b	0.61b
P_3	0.86b	1.29a	2.26a	0.77a
CV (%)	4.04	5.23	3.68	4.33

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. Total phosphorus content in soybean plant

4.11.1 Effect of P on phosphorus content in soybean plant

A statistically significant variation was observed on phosphorus concentration in soybean plant with different doses of phosphorus (Table 4.7). However, the highest phosphorus concentration (1.290%) among the different doses of phosphorus was recorded in P_3 (50 kg P ha^{-1}). On the other hand, the lowest phosphorus concentration in soybean plant (0.530%) was recorded in the P_0 treatment where no phosphorus was applied. Bhakare and Sonar (2000) reported that the highest grain and straw soybean yields (32.1 and 64.9 q ha^{-1}, respectively), P uptake in grain and straw (12.9 and 14.6 q ha^{-1}, respectively) and soil available P (14.6 kg ha^{-1}) were recorded from the 100 kg P_2O_5 ha^{-1} treatment. The results showed that inorganic forms of P contribute to increased P availability and uptake in soybean and increased yields.

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 4.8). However, the highest phosphorus concentration (1.023%) among the different doses of sulphur was recorded in S_3 (40 kg S ha^{-1}). On the other hand, the lowest phosphorus concentration in soybean plant (0.8075%) was recorded in the S_0 treatment where no S was applied.

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

Significant effect of combined application of different doses of P and S fertilizers on the phosphorus concentration was observed in the soybean plant (Table 4.9). However, the highest concentration of phosphorus in the soybean plant (1.380%) was recorded with the P_3S_3 (50 kg P ha^{-1} + 40 kg S ha^{-1}) which were statistically similar with P_3S_2 (50 kg P ha^{-1} + 20 kg S ha^{-1}) and P_3S_1 (50 kg P ha^{-1} +10 kg S ha^{-1}) treatment combinations. On the other hand, the lowest phosphorus concentration in soybean plant (0.4800%) was observed in P_0S_0 treatment combinations.

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

Treatments	Total N (%)	Total P (%)	Total K (%)	Total S (%)
S_0	0.40d	0.80c	1.68c	0.32c
S_1	0.86c	0.93b	2.09b	0.49b
S_2	1.00a	0.99a	2.39a	0.70a
S_3	0.96b	1.02a	2.34a	0.71a
CV (%)	4.04	5.23	3.68	4.33

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 Total potassium content in soybean plant

4.11.1 Effect of P on potassium content in soybean plant

Application of P showed significant variation on the potassium concentration in soybean plant (Table 4.7). The highest potassium concentration in soybean plant (2.265%) was recorded in P_3 (50 kg P ha^{-1}) treatment. On the other hand, the lowest potassium concentration in soybean plant (2.020%) was recorded in the P_0 treatment where no phosphorus was applied. The highest potassium concentration was observed due to the positive effect of phosphorus on potassium content in soybean plant up to its highest level in this experiment..

4.11.2 Effect of S on potassium content in soybean plant

A statistically significant variation was observed on potassium concentration in soybean plant with different doses of sulphur (Table 4.8). However, the highest potassium concentration (2.390%) among the different doses of sulphur was recorded in S_2 (20 kg S ha^{-1}). On the other hand, the lowest potassium concentration in soybean plant (1.680%) 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 P and S on potassium content in soybean plant

Significant effect of combined application of different doses of P and S fertilizers on the potassium concentration was observed in the soybean plant (Table 4.9). The highest concentration of potassium in the soybean plant (2.580%) was recorded with the P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) which were statistically similar with P_1S_3 (15 kg P ha^{-1} + 40 kg S ha^{-1}) and P_3S_2 (50 kg P ha^{-1} + 20 kg S ha^{-1}) treatment combinations. On the other hand, the lowest potassium concentration (1.560%) in soybean plant was observed in P_0S_0 treatment combinations. This might be due to the fact that, the combined effect of both phosphorus and sulphur played positive effect on potassium content in soybean plant up to certain limit.

4.12 Total sulphur content in soybean plant

4.12.1 Effect of P on sulphur content in soybean plant

Application of P showed significant variation on the sulphur concentration in soybean plant (Table 4.7). The highest sulphur concentration in soybean plant (0.7708%) was recorded in P_3 (50 kg P ha^{-1}) treatment. On the other hand, the lowest sulphur concentration in soybean plant (0.4198%) was recorded in the P_0 treatment where no phosphorus was applied. The highest sulphur concentration was observed due to the positive effect of phosphorus on sulphur content in soybean plant up to maximum limit of this experiment.

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 4.8). The highest sulphur concentration among the treatments of sulphur (0.7175%) was observed in S_3 (40 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 (0.3238%) 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 due to the application of S up to its highest limit in this experiment.

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

Significant effect of combined application of different doses of P and S fertilizers on the sulphur concentration was observed in the soybean plant (Table 4.9). The highest concentration of sulphur in the soybean plant (0.9410%) was recorded with the P_3S_3 (50 kg P ha^{-1} + 40 kg S ha^{-1}) treatment combination. On the other hand, the lowest sulphur concentration (0.285%) in soybean plant was observed in P_0S_0 treatment combination. This might be due to the fact that, the combined effect of both phosphorus and sulphur played positive effect on sulphur content in soybean plant up to its maximum level of treatment combination.

Table4.9: Interaction effect of P and S on the total N, P, K and S contents in soybean plant

Treatments	Total N (%)	Total P (%)	Total K (%)	Total S (%)
P_0S_0	0.31h	0.48h	1.56f	0.28h
P_0S_1	0.54g	0.50h	1.91e	0.34fg
P_0S_2	0.69f	0.59g	2.24d	0.49e
P_0S_3	0.86e	0.55gh	2.31cd	0.56d
P_1S_0	0.35h	0.71f	1.62f	0.29h
P_1S_1	0.69f	0.77ef	2.05e	0.32gh
P_1S_2	1.07b	0.79e	2.25d	0.54de
P_1S_3	0.94cd	0.91d	2.54ab	0.52de
P_2S_0	0.36h	0.97d	1.62f	0.34fg
P_2S_1	1.24a	1.11c	2.01e	0.38f
P_2S_2	1.29a	1.22b	2.58a	0.89ab
P_2S_3	1.07b	1.25b	2.31cd	0.83c
P_3S_0	0.59g	1.07c	1.92e	0.37fg
P_3S_1	0.91d	1.35a	2.42bc	0.90ab
P_3S_2	1.00c	1.36a	2.53ab	0.87bc
P_3S_3	0.96cd	1.38a	2.19d	0.94a
CV (%)	4.04	5.23	3.68	4.33

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 Protein content in soybean seed

4.14.1 Effect of P on protein content in soybean seed

A statistically significant variation was observed in protein content in seed of soybean with different doses of phosphorus (Table 4.10). Among the different doses of phosphorus the highest protein content in seed (42.52%) was recorded in P_3 (50 kg P ha^{-1}) treatment. On the other hand, the lowest protein content in seed (40.63%) was recorded in the P_0 treatment where no phosphorus was applied. The above findings are similar to those of Satter and Ahmed (1992) who reported that application of 30 kg P ha^{-1} increased total protein content in soybean.

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

Treatments	Protein content (%)	Oil content (%)
P_0	40.63 c	19.08 b
P_1	41.59 b	19.87 b
P_2	42.26 ab	21.26 a
P_3	42.52 a	21.02 a
CV (%)	2.34	5.05

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 4.11). The highest protein content in seed (43.64%) among different doses of S fertilizer was recorded with S_3 (40 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 (39.33%) 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 4.11 Effect of S on protein and oil content of soybean

Treatments	Protein content (%)	Oil content (%)
S_0	39.33 c	19.28 c
S_1	40.90 b	19.92 bc
S_2	43.14 a	21.16 a
S_3	43.64 a	20.86 ab
CV (%)	2.34	5.05

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 P and S on protein content in soybean seed

Significant effect of combined application of different doses of P and S fertilizers on the protein content was observed in seed of soybean (Table 4.12 and Fig.9). The highest protein content in the seed (44.88%) was recorded with the P_2S_3 (30 kg P ha^{-1} + 40 kg S ha^{-1}) treatment combination .On the other hand, the lowest protein content (37.42%) in seed was observed in P_0S_0 treatment combination. Tomar *et al.* (2004) Majumdar *et al.*(2001) found that the increased rate of P and S significantly increased the protein content

4.15 Oil content in soybean seed

4.15.1 Effect of P on oil content in soybean seed

A statistically significant variation was observed in oil content in seed of soybean with different doses of phosphorus (Table 4.10). Among the different doses of phosphorus the highest oil content in seed (21.26%) was recorded in P_2 (30 kg P ha^{-1}) treatment which was statistically similar with P_3 (50 kg ha^{-1}) treatment. On the other hand, the lowest oil content in seed (19.08%) was recorded in the P_0 treatment where no phosphorus was applied. Dubey and Khan. (1991) found that oil content increased from 19.05 to 21.09 with increase in phosphorus rate.

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

Treatments	Protein content (%)	Oil content (%)
P_0S_0	37.42 g	17.84 e
P_0S_1	40.63ef	18.31 de
P_0S_2	42.35 b-e	20.36 a-c
P_0S_3	42.11 de	19.80 b-d
P_1S_0	40.16 f	18.73 c-e
P_1S_1	40.22 f	19.73 b-d
P_1S_2	42.44 b-d	20.32 a-c
P_1S_3	43.55 a-d	20.68 a-c
P_2S_0	39.99 f	20.12b-d
P_2S_1	40.56ef	21.00 ab
P_2S_2	43.63 a-d	22.26 a
P_2S_3	44.88 a	21.66 ab
P_3S_0	39.77 f	20.42 a-c
P_3S_1	42.20 c-e	20.64 a-c
P_3S_2	44.12 ab	21.69 ab
P_3S_3	44.01a-c	21.32 ab
CV (%)	2.34	5.05

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

The effect of different doses of sulphur showed statistically significant variation on the oil content in seed of soybean (Table 4.11). The highest oil content in seed (21.16%) 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 (19.28%) was observed in the S_0 (control condition) treatment. Tomar *et al.* (2000) reported that the highest oil content (20.51%) was recorded with the application of 50 kg S ha^{-1} regardless of sources. Gokhale *et al.* (2005) reported that application of 30 kg S ha^{-1} increased oil content in soybean seed over control.

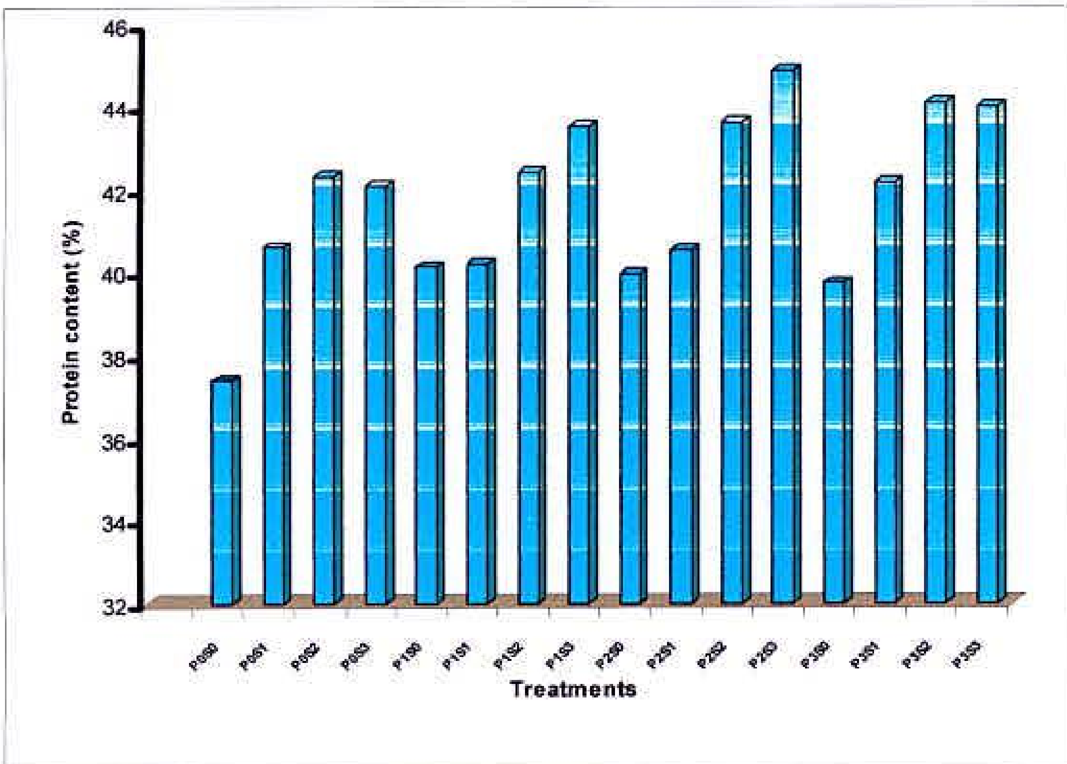

Fig.10. Combined effect of P and S on protein content (%) of soybean

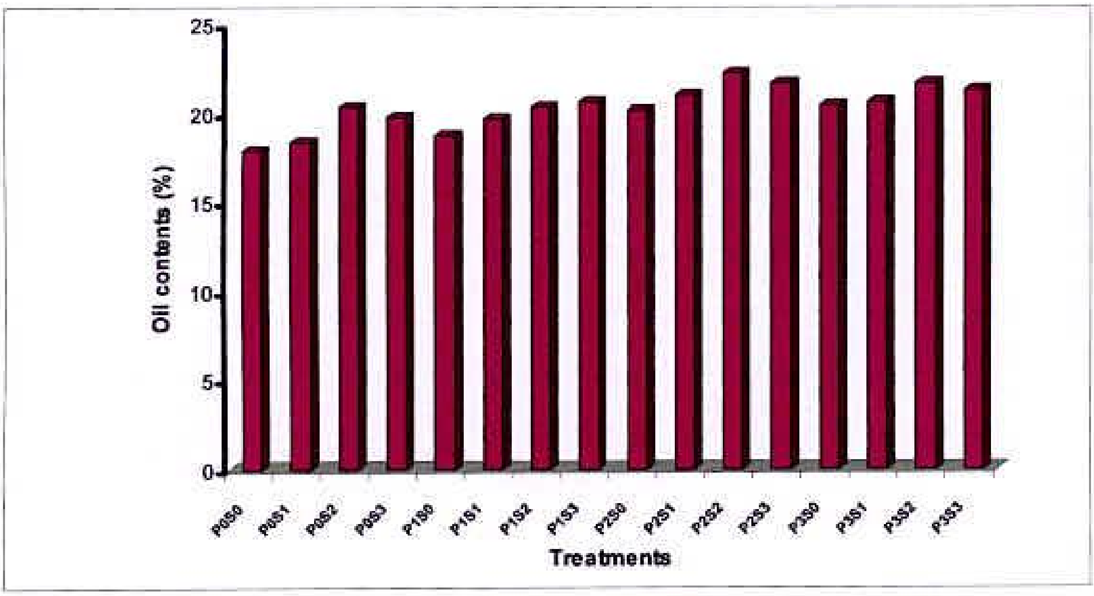

Fig.11. Combined effect of P and S on oil content (%) of soybean

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

Significant effect of combined application of different doses of P and S fertilizers on the oil content was observed in seed of soybean (Table 4.12 and Fig.10). The highest oil content in the seed (22.26%) was recorded with the P_2S_2 (40 kg P ha^{-1} + 20 kg S ha^{-1}) treatment combination. On the other hand, the lowest oil content (17.84%) in seed was observed in P_0S_0 treatment combination. Tomar *et al.* (2004) and Majumdar *et al.*(2001) also found that the increaseed P and S levels significantly increased the oil content. Majumdar *et al.*(2001) also reported that application of 60 kg P_2O_5 along with 40 kg S ha^{-1} was the optimum rate of P and S to obtain the highest yield.

4.16 Effect of phosphorus on pH and nutrient status of the post harvest soil of soybean field

4.16.1 Effect of phosphorus on pH in the post harvest soil of soybean field

No significant variation was observed in pH in soil of soybean field with different doses of P (Table 4.13). Considering the different doses of P the pH in soil (6.253) was recorded in P_2 (30 kg P ha^{-1}) which was statistically similar with P_0 (control), P_3 (50 kg P ha^{-1}) and P_1 (15 kg P ha^{-1}) treatments.

4.16.2 Effect of phosphorus on organic carbon content in the post harvest soil of soybean field

No significant variation was observed in organic carbon content in post harvest soil of soybean field with different doses of P (Table 4.13) . Considering the different doses of P the highest organic carbon content in soil (1.057 %) was recorded in P_2 (30 kg P ha^{-1}) treatment which was statistically similar with all other treatments.

4.16.3 Effect of phosphorus 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 P (Table 4.13). Considering the different doses of P the highest nitrogen concentration in soil (0.118%) was recorded in P_3 (50 kg P ha^{-1}) which was statistically similar with P_2 and P_1 treatments. On the other hand, the lowest nitrogen concentration in soil (0.106%) was recorded in the P_0 treatment where no phosphorus was applied.

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

A statistically significant variation was observed in phosphorus concentration in soil of soybean field with different doses of P (Table 4.13). Considering the different doses of P the highest phosphorus concentration in soil (0.00657%) was recorded in P_3 (50 kg P ha^{-1}) which was statistically similar with P_2 treatment. On the other hand, the lowest phosphorus concentration in soil (0.00450%) was recorded in the P_0 treatment where no phosphorus was applied. Slaton *et al.* (2001) also observed that compared to the untreated control, soil test P increased as P application rate increased. Bhakare and Sonar (2000) reported that the soil available P (14.6 kg ha^{-1}) was increased from the 100 kg P_2O_5 ha^{-1} treatment. The results showed that inorganic forms of P contribute to increased P availability and uptake in soybean and increased yields.

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

A statistically significant variation was observed in potassium concentration in soil of soybean field with different doses of P (Table 4.13). Considering the different doses of P the highest potassium concentration in soil (0.03553%) was recorded in P_3 (50 kg P ha^{-1}) which was statistically similar with P_2 treatment.. On the other hand, the lowest potassium concentration in soil (0.3%) was recorded in the P_0 treatment where no phosphorus was applied. Sonar and Bhakare (2004) found the similar results that the increased P applications also increased the available K status and were highest for 75 and 100 kg P_2O_5 ha^{-1} (412 and 420 kg P_2O_5 ha^{-1}, respectively) and were at par at each other.

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

A statistically significant variation was observed in sulphur concentration in soil of soybean field with different doses of P (Table 4.13). Considering the different doses of P the highest potassium concentration in soil (0.004575%) was recorded in P_2 (30 kg P ha^{-1}) was statistically similar with P_3 (50 kg P ha^{-1}) treatment. On the other hand, the lowest sulphur concentration in soil (0.003208%) was recorded in the P_0 treatment where no phosphorus was applied.

Table 4.13 Effect of P on the soil pH, organic C, total N, available P, available K and available S contents of the post harvest soil

Treatments	Soil pH	Organic C (%)	Total N (%)	Available P (%)	Available K (%)	Available S (%)
P_0	6.2	1.00	0.09b	0.004c	0.027c	0.003c
P_1	6.2	1.01	0.11a	0.005b	0.030b	0.004b
P_2	6.2	1.05	0.13a	0.006a	0.034a	0.005a
P_3	6.2	1.00	0.12a	0.006a	0.035a	0.004a
CV (%)	1.53	4.31	4.66	4.21	5.08	6.36

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 pH and nutrient status of the post harvest soil of soybean field

4.17.1 Effect of sulphur on the pH in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizer showed no significant variation in pH in post harvest soil (Table 4.14). Among the different treatments, S_0 (no S) showed the pH (6.255) in soil which were statistically similar with S_1, S_2 and S_3 treatments. Sharma *et. al.* (2004) observed that the rates and sources of S did not significantly vary for their effects on soil pH.

4.17.2 Effect of sulphur on organic carbon content in the post harvest soil of soybean field

The effect of different doses of sulphur fertilizer showed a statistically significant variation in the carbon concentration in post harvest soil (Table 4.14). Among the different treatments, S_2 (20 kg S ha^{-1}) showed the highest organic carbon (1.1%) in soil which was statistically similar with S_3 (40 kg S ha^{-1}) treatment. The lowest organic carbon (0.96%) in soil was observed in the treatment S_0 where no S fertilizer was applied.

4.17.3 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 4.14). Among the different treatments, S_3 (40 kg S ha^{-1}) showed the highest nitrogen concentration (0.1260%) in soil which was statistically similar with S_2 (20 kg S ha^{-1}) and S_1 (10 kg S ha^{-1}) treatments. The lowest nitrogen concentration (0.09025%) in soil was observed in the treatment S_0 where no S fertilizer was applied. Vijayapriya *et al.* (2005) reported that the uptake of N by soybean and its availability in soil increased with S levels and the highest values were recorded at 30 kg Sha^{-1}. Kulhare and Kaura.(2000) reported that the availability of N, K and S in the soil surface increased with S application.

4.17.4 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 significant variation in the phosphorus concentration in post harvest soil (Table 4.14). Among the different treatments, S_3 (40 kg S ha^{-1}) showed the highest phosphorus concentration (0.0063%) in soil which was statistically similar with S_2 (20 kg S ha^{-1}). The lowest phosphorus concentration (0.005125%) in soil was observed in the treatment S_0 where no S fertilizer was applied. Vijayapriya *et al.* (2005)

reported that the uptake of P by soybean and its availability in soil increased with S levels and the highest values were recorded at 30 kg Sha^{-1}. Kulhare and Kaura.(2000) reported that the availability of N, K and S in the soil surface increased with S application while ammonium sulfate was better than gypsum for P and S availability in the soil and soybean nutrient uptake.

4.17.5 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 significant variation in the potassium concentration in post harvest soil (Table 4.14). Among the different treatments, S_3 (40 kg S ha^{-1}) showed the highest potassium concentration (0.033%) in soil which was statistically similar with S_2 (20 kg S ha^{-1}) and S_1 (10 kg S ha^{-1}) treatments. The lowest K concentration (0.029%) in soil was observed in the treatment S_0 where no S fertilizer was applied. Vijayapriya *et al.* (2005) reported that the uptake of K by soybean and its availability in soil increased with S levels and the highest values were recorded at 30 kg S ha^{-1}. Kulhare and Kaura.(2000) reported that the availability of K in the soil surface increased with S application .

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

Treatments	Soil pH	Organic C (%)	Total N (%)	Available P (%)	Available K (%)	Available S (%)
S_0	6.2	0.96b	0.09b	0.005c	0.028b	0.002d
S_1	6.2	0.99b	0.11a	0.005b	0.031a	0.003c
S_2	6.2	1.06a	0.12a	0.006ab	0.033a	0.004b
S_3	6.1	1.06a	0.12a	0.006a	0.033a	0.005a
CV (%)	1.53	4.31	4.66	4.21	5.08	6.36

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

4.17.6 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 significant variation in the sulphur concentration in post harvest soil (Table 4.14). Among the different treatments, S_3 (40 kg S ha^{-1}) showed the highest sulphur concentration (0.005125%) in soil. The lowest sulphur concentration (0.002483%) in soil was observed in the treatment S_0 where no S fertilizer was applied. Vijayapriya *et al.* (2005) reported that the uptake of S by soybean and its availability in soil increased with S levels and the highest values were recorded at 30 kg S ha^{-1}. Kulhare and Kaura.(2000) reported that the availability of N, K and S in the soil surface increased with S application while ammonium sulfate was better than gypsum for P and S availability in the soil and soyban nutrient uptake.

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

Treatments	Soil pH	Organic C (%)	Total N (%)	Available P (%)	Available K (%)	Available S (%)
P_0S_0	6.23	0.95	0.078b	0.004i	0.025d	0.001h
P_0S_1	6.30	0.98	0.11ab	0.004hi	0.026d	0.003f
P_0S_2	6.24	1.01	0.11ab	0.005gh	0.028cd	0.004d
P_0S_3	6.19	1.05	0.12a	0.005fg	0.028cd	0.004c
P_1S_0	6.24	0.97	0.09ab	0.005gh	0.028cd	0.002g
P_1S_1	6.20	0.99	0.10ab	0.006de	0.030c	0.003e
P_1S_2	6.16	1.02	0.12a	0.006b-e	0.030c	0.004bc
P_1S_3	6.21	1.07	0.13a	0.006a-d	0.031c	0.004bc
P_2S_0	6.28	0.96	0.09ab	0.006ef	0.030c	0.003ef
P_2S_1	6.23	1.04	0.12ab	0.0064a-d	0.035b	0.004d
P_2S_2	6.30	1.10	0.13a	0.007ab	0.036ab	0.005a-c
P_2S_3	6.20	1.11	0.12a	0.007a	0.035ab	0.005a
P_3S_0	6.27	0.97	0.09ab	0.006c-e	0.030c	0.003ef
P_3S_1	6.26	0.97	0.12a	0.006ab	0.036ab	0.003de
P_3S_2	6.17	1.10	0.12a	0.006a-c	0.037ab	0.005a-c
P_3S_3	6.19	1.01	0.13a	0.006a	0.038a	0.005ab
CV (%)	1.53	4.31	4.66	4.21	5.08	6.36

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

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

4.18.1 Interaction effect of phosphorus and sulphur on the pH in the post harvest soil of soybean field

The combined effect of different doses of phosphorus and sulphur fertilizer did not show any significant variation in pH in post harvest soil (Table 4.14). Among the different treatments, P_2S_2 (30 kg P ha^{-1}+20 kg S ha^{-1}) showed the pH value (6.30) in soil which was statistically similar with all other treatment combinations.

4.18.2 Interaction effect of phosphorus and sulphur on organic carbon content in the post harvest soil of soybean field

The combined effect of different doses of phosphorus and sulphur fertilizer showed no significant variation in the organic carbon content in post harvest soil (Table 4.14). Among the different treatments, P_3S_2 (50 kg P ha^{-1} +20 kg S ha^{-1}) showed the highest organic carbon content (1.13%) in soil which was statistically similar with all other treatment combinations.

4.18.3 Interaction effect of phosphorus and sulphur on total nitrogen content of the post harvest soil of soybean field

Significant variation was observed due to the combined application of different doses of P and S fertilizers on the nitrogen concentratio in post harvest soil of soybean field (Table 4.15). The highest concentration of nitrogen (0.13%) in the post harvest soil was recorded with the P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}) treatment which was statistically similar with all other treatment combinations except the control treatment combination. Dwivedi and Bapat (1996) reported that the concentrations of N in soil increased with increasing P and S rates.

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

Significant effect of combined application of different doses of P and S fertilizers on the phosphorus concentration was observed in post harvest soil of soybean field (Table 4.15). The highest concentration of phosphorus (0.0069%) in the post harvest soil was recorded with the P_3S_3 (50 kg P ha^{-1} + 40 kg S ha^{-1}) treatment which was statistically similar with many of the treatment combinations. On the other hand, the lowest phosphorus concentration (0.0040%) in the post harvest soil was observed in P_0S_0 treatment combination. Dwivedi and Bapat (1996) reported that the concentrations of P in soil increased with increasing P and S rates.

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

Significant effect of combined application of different doses of P and S fertilizers on the potassium concentration was observed in post harvest soil of soybean field (Table 4.15). The highest concentration of potassium (0.03870%) in the post harvest soil was recorded with the P_3S_3 (50 kg P ha^{-1} + 40 kg S ha^{-1}) treatment. On the other hand, the lowest potassium concentration (0.02530%) in the post harvest soil was observed in P_0S_0 treatment. Dwivedi and Bapat (1996) reported that the concentrations of K in soil increased with increasing P and S rates.

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

Significant effect of combined application of different doses of P and S fertilizers on the sulphur concentration was observed in post harvest soil of soybean field (Table 4.15). The highest concentration of sulphur (0.0055%) in the post harvest soil was recorded with the P_2S_3 (30 kg P ha^{-1} + 40 kg S ha^{-1}) treatment. On the other hand, the lowest sulphur concentration (0.001033%) in the post harvest soil was observed in P_0S_0 treatment. Dwivedi and Bapat (1996) reported that the concentrations of S in soil increased with increasing P and S rates.

Chapter V

Summary and Conclusion

Chapter V

SUMMARY AND CONCLUSION

With a view to investigating the effect of phosphorus and sulphur fertilizers on the growth, yield and oil content of soybean 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 2008. The soil was clay loam in texture having pH 6.4 and organic matter content of 0.78%, 0.06% total nitrogen, 10.27 ppm available P, exchangeable K 0.0114 meq/100 gm soil and 19.62 ppm available Sulphur contents.

The experiment was laid out following two factors randomized complete block design with 16 treatments having unit plot size of 2.5 m x 2.0 m (5.0 m^2) and replicated three times. Two factors were phosphorus and sulphur. The treatment combinations were P_0S_0 Control (without P and S), P_0S_1 (0 kg P ha^{-1} + 10 kg S ha^{-1}), P_0S_2 (0 kg P ha^{-1} + 20 kg S ha^{-1}), P_0S_3 (0 kg P ha^{-1} + 40 kg S ha^{-1}), P_1S_0 (15 kg P ha^{-1} + 0 kg S ha^{-1}), P_1S_1 (15 kg P ha^{-1} +10 kg S ha^{-1}), P_1S_2 (15 kg P ha^{-1} + 20 kg S ha^{-1}), P_1S_3 (15 kg P ha^{-1} + 40 kg S ha^{-1}), P_2S_0 (30 kg P ha^{-1} + 0 kg S ha^{-1}), P_2S_1 (30 kg P ha^{-1} + 10 kg S ha^{-1}), P_2S_2 (30 kg P ha^{-1} + 20 kg S ha^{-1}), P_2S_3 (30 kg P ha^{-1} + 40 kg S ha^{-1}), P_3S_0 (50 kg P ha^{-1} + 0 kg S ha^{-1}), P_3S_1 (50 kg P ha^{-1} + 10 kg S ha^{-1}), P_3S_2 (50 kg P ha^{-1} + 20 kg S ha^{-1}) and P_3S_3 (50 kg P ha^{-1} + 40 kg S ha^{-1}).

Each plot received recommended doses of N, K, Zn and B (30 kg N ha^{-1} from urea, 40 kg K ha^{-1} from MP, 2 kg Zn ha^{-1} from ZnO and 1 kg B from Boric acid ha^{-1}, respectively). The elements P and S were applied in the form of TSP and Gypsum.

The whole amount of MP, 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 20 days of germination. The required amounts of P (from TSP) 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.

Soybean seeds were sown on the 27th December 2008 in lines following the recommended line-to-line distance of 30 cm and plant-to-plant distance of 5 cm and the crop was harvested on 14th April 2009. Intercultural operations were done whenever required in order to support normal plant growth. Ten plants were randomly collected to record the data plot wise for plant height (cm), number of leaves plant^{-1}, number of primary branches plant^{-1}, number of pods plant^{-1}, number of seeds plant^{-1}, thousand seed weight (g), grain yield (t ha^{-1}) and stover yield (t ha^{-1}) and biological yield(t ha^{-1}).

The post harvest soil samples from 0-15 cm depth were collected plot wise and analyzed for pH, organic carbon, total N, available P, available K and available S contents. Plant samples were also chemically analyzed for total N, P, K and S contents. Oil and protein content of soybean seed were also determined. All the data were statistically analyzed following F-test and the mean comparison was made by DMRT.

The results of the experiment are stated below:

Yield and Yield attributes

The effect of different levels of sulphur and phosphorus individually was significant in relation to yield and yield attributes studied. Plant height was significantly affected by different levels of P and S. Plant height increased with increasing levels of P and S up to highest level. The individual application of P @ 50 kg ha^{-1} (P_3) produced the tallest plant (68.50 cm), whereas application of S @ 40 kg ha^{-1} (S_3) produced the tallest plant of (68.21 cm) height. The tallest plant (70.35cm) was found in P_3S_3 treatment combination, which was higher over control treatment combination (60.87 cm).

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

Like all other plant characters, grain yield of soybean was influenced significantly due to application of P and S. Grain yield was increased with increasing levels of P and S up to certain level. The highest grain yield (2.046 t ha^{-1}) was found in plants receiving P @ 30 kg ha^{-1} and the lowest was recorded in P_0 treatment. The individual application of S @ 20 kg ha^{-1} produced the highest amount of grain yield (2.068 t ha^{-1}). The combined application of P and S had positive effect on grain yield of soybean. The highest grain yield of soybean (2.297 t ha^{-1}) was recorded in P_2S_2 treatment. The lowest yield (1.327 t ha^{-1}) was recorded in P_0S_0 treatment. Combined application of P @ 30 kg ha^{-1} and S @ 20 kg ha^{-1} produced higher grain yield compared to control treatment significantly.

Nutrient, Protein and Oil content

Application of P and S significantly increased the Protein content in seeds of soybean. The range of protein content in seeds varied from 37.42 % in P_0S_0 to 44.88 % in P_2S_3 treatment. Combined application of P @ 30 kg ha^{-1} and S @ 40 kg ha^{-1} produced higher protein content in seed compared to control treatment significantly. However, highest protein content was obtained (43.64%) at S @ 40 kg ha^{-1} .This was statistically similar with S@ 20 kg ha^{-1}. So it was wise to use S @20 kg ha^{-1}.

Application of P and S significantly increased the Oil content in seeds of soybean. The range of oil content in seeds varied from 17.84% in P_0S_0 to 22.26% in P_2S_2 treatment combination. Application of P@ 30 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, and S) in plant samples were significantly affected due to P and S fertilization. The interaction effect of P and S was also found remarkable. The N, P, K and S contents in plant samples varied from 0.318% in P_0S_0 to 1.294% in P_2S_2, 0.48% in P_0S_0 to 1.380% in P_3S_3, 1.560% in P_0S_0 to 2.580% in P_2S_2, 0.285% in P_0S_0 to 0.94% in P_3S_3 treatment combinations respectively. Nitrogen, Phosphorus, Potassium and Sulphur contents in plant samples increased with increasing levels of P and S up to certain level.

Different levels of P and S application also influenced nutrient content in post harvest soil. The content of total N, available P, available K and available S of post harvest soil varied from 0.95 to 1.13%, 0.078% to 0.130%, 0.004% to 0.006%, and 0.025% to 0.038% and 0.001% to 0.005% respectively due to combined application of P and S at different levels. The addition of P and S not only increased the yield but also protected the soil from total exhaustion of nutrients. The interaction effect of P and S on soil pH and organic C content in post harvest soil were not significant. But individual application of S showed significant effect on organic carbon content in post harvest soil at highest value.

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

Significantly higher growth and yield performance and oil content of soybean was observed by the P_2S_2 treatment i.e., by the combined application of phosphorus and sulphur fertilizers @ 30 kg P ha^{-1} and 20 kg S ha^{-1}. In some cases the highest results obtained at P_3S_3 treatment combination i.e. , @ 50 kg P ha^{-1} and 40 kg S ha^{-1} which were very close to the results obtained by the P_2S_2 treatment. Considering the findings it is wise and economic to adopt P_2S_2 treatment i.e., by the combined application of phosphorus and sulphur fertilizers @ 30 kg P ha^{-1} and 20 kg S ha^{-1} and avoid the luxurious doses of phosphorus and Sulphur.

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

In order to produce higher grain, yield and quality soybean and also to maintain soil fertility and productivity the combined application of phosphorus and sulphur fertilizers @ 30 kg P ha^{-1} and 20 kg S ha^{-1} may be done in Tejgaon series under AEZ No.28 than their individual applications.

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

Further suggestion: -

In order to make this work more useful and beneficial for the farmers, the following aspects also be considered in future.

1. Biofertilizer should be inoculated which helps nitrogen fixation.
2. Plant density should be maintained properly
3. Varietal trial needs to be investigated.
4. Other nutrient interactions should also be investigated.

Chapter VI

References

Chapter - VI

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Chapter VII

Appendices

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APPENDICES

Appendix Table I. Monthly records of meteorological observation at the period of experiment November, 2008 to February, 2009)

Month	Temperature (^0C)		Humidity	Precipitation	Potential	Solar
	(Maximum)	(Minimum)	(%)	(mm)	Evapotranspiration (mm/day)	radiation ($Mj/m^2/d$)
November	30.20	20.13	83.30	31	2.966	15.364
December	26.60	13.5	81.00	9	2.43	14.089
January	25.40	12.93	78.00	7	2.387	14.766
February	25.30	14.2	73.68	7	2.37	14.866

Source: Weather Yard, Bangladesh Metrological department, Dhaka.

Appendix Table II. Summary of analysis of variance of growth parameters of soybean as influenced by different level of phosphorus 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	6.334	0.009	1.406	1.956	62.787
Factor A	3	51.215**	3.391**	3.096*	432.605**	1700.419**
Factor B	3	66.728**	1.770**	7.495**	98.643**	344.122**
AB	9	2.642**	0.129*	1.069*	9.692**	32.375*
Error	30	1.802	0.053	0.842	0.898	40.935

Appendix Table III. Summary of analysis of variance of yield attributes of soybean as influenced by different level of phosphorus and sulphur

Source of variation	Degrees of freedom	Mean square			
		1000 seed weight (g)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield(t ha^{-1})
Replication	2	0.612	0.021	0.004	0.039
Factor A	3	58.389**	0.726**	0.524**	2.374**
Factor B	3	35.045**	0.700**	0.467**	2.048**
AB	9	1.572*	0.017*	0.070**	0.084**
Error	30	1,141	0.008	0.008	0.014

Appendix Table IV. Summary of analysis of variance of nutrient concentration of soybean plant as influenced by different level of phosphorus and sulphur

Source of variation	Degrees of freedom	Mean square			
		Total N (%)	Total P (%)	Total K (%)	Total S (%)
Replication	2	0.001	0.001	0.069	0.000
Factor A	3	0.318**	1.402**	0.123**	0.343**
Factor B	3	0.895**	0.108**	1.274**	0.423**
AB	9	0.078**	0.011**	0.090**	0.049**
Error	30	0.001	0.002	0.006	0.001

Appendix Table V. Summary of analysis of variance of pH, organic carbon and nutrient content of post harvest soil as influenced by different level of phosphorus and sulphur

Source of variation	Degrees of freedom	Mean square					
		pH	Organic C (%)	Total N (%)	Available P (%)	Available K (%)	Available S (%)
Replication	2	0.006	0.001	0.000	0.00001	0.0000	0.00001
Factor A	3	0.006NS	0.007NS	0.000**	0.00105**	0.0019**	0.00044**
Factor B	3	0.009NS	0.026**	0.003**	0.00030**	0.0006**	0.00174**
AB	9	0.005NS	0.003NS	0.000*	0.00001**	0.0000**	0.00005**
Error	30	0.009	0.003	0.000	0.00001	0.0000	0.00001

Appendix Table VI. Summary of analysis of variance of protein content and oil content of soybean as influenced by different level of phosphorus and sulphur

Source of variation	Degrees of freedom	Mean square	
		Protein content (%)	Oil content (%)
Replication	2	1.613	3.445
Factor A	3	8.610**	12.483**
Factor B	3	48.146**	8.976**
AB	9	1.686**	0.356*
Error	30	0.955	1.050