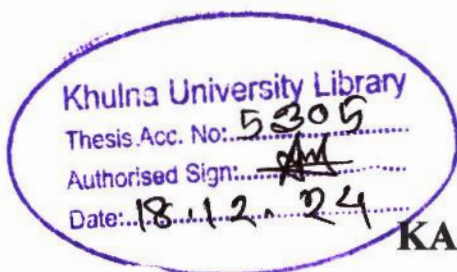


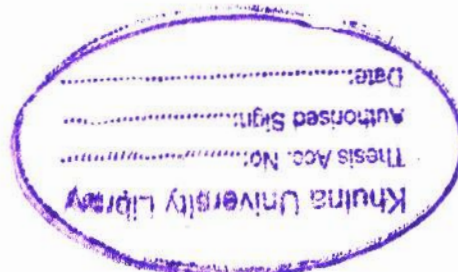
**EFFECT OF SULPHUR AND PHOSPHORUS
FERTILIZER ON GROWTH AND NUTRITIONAL QUALITY
OF SOYBEAN AS LIVESTOCK FEED**



A Thesis

by

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Examination Roll No: MS-230836

**A thesis (Course No. AN-6104) submitted to the Agrotechnology Discipline
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Dedicated to

My beloved parents, who sacrificed for me, inspired and
blessed me in every way of my life.

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ABSTRACT

A field experiment was conducted at Professor Dr. Purnendu Gain Field Laboratory, Khulna University during the period from November 2023 to February 2024 to evaluate the effect of Sulphur and phosphorous fertilizer on the growth, yield and seed nutritional quality of soybean. BINA soybean-5 was used as test crop. The experiment comprised three levels of Sulphur (0, 6.51, 9.76 kg ha⁻¹) and three levels of Phosphorous viz. (0, 14, 21 kg ha⁻¹). Altogether there were 9 treatment combinations and laid out following the randomized complete block design with three replications. Individual application of different levels of sulphur and phosphorus showed non-significant effect in relation to the most of the yield and yield attributes studied. Plant height, number of branches per plant, number of leaves per plant, stem diameter, pod length, number of pods per plant, number of seeds per plant, hundred seed weight, grain yield, stover yield and biological yield, were increased by the application of S up to 9.77 kg ha⁻¹. The chlorophyll content showed significant effect on individual application of sulphur and phosphorous. Pods per plant was also highly significant on both individual and interaction of S and P application of fertilizer. Seeds per pod and seed yield showed also significant effect on individual application of sulphur and phosphorous. On the other hand, plant height, number of branches per plant, number of leaves per plant, stem diameter, pod length, number of pods per plant, number of seeds per plant, hundred seed weight, grain yield, stover yield and biological yield, were increased at the rate of 21 kg P ha⁻¹ in most cases. Interaction effects of sulphur and phosphorus on yield attributes were increased. Most of the growth, yield attributing parameters found to be increased by the combined application of 9.77 kg S ha⁻¹ and 21 kg P ha⁻¹. The percentage of dry matter, crude protein, crude fiber, ether extract were increased with the increasing level of S and P fertilizers. The nitrogen, phosphorous, potassium, sulphur and iron content in the seed also increased with the increasing level of sulphur and phosphorous fertilizer.

Keywords: Sulphur, Phosphorous, Soybean, Nutritional Quality and Growth and yield attributes

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Abbreviation and non-English Word

Abbreviated form	Elaborated Form
%	Percentage
Ha	Hectare
Cm	Centimeter
M	Meter
Kg	Kilogram
MT	Metric Ton
ANOVA	Analysis of variance
BAU	Bangladesh Agricultural University
BLRI	Bangladesh Livestock Research Institute
DM	Dry Matter
CF	Crude Fiber
CP	Crude Protein
NFE	Nitrogen Free Extract
EE	Ether Extract
GE	Gross Energy
DMRT	Duncan New Multiple Range Test
et al	Et alli; Latin word meaning “and others”
FAO	The Food and Agriculture Organization
MJ	Megajoule
N	Nitrogen
P	Phosphorus
S	Sulphur
K	Potassium
Fe	Iron
RCBD	Randomized Complete Block Design

CHAPTER I

INTRODUCTION

Soybean (*Glycine max*) is a versatile and economically important legume crop that belongs to the Fabaceae family. Soybeans have been native to East Asia and have been farmed for thousands of years. Because of their wide range of uses in food, feed, and industrial products, soybeans have become an essential part of modern agricultural systems. (Hartman *et al.*, 2011). Due to their global significance as a key source of food, high-protein feed, and edible vegetable oil, soybeans are essential for both human and animal nutrition. Its seed has 18–20% edible oil, 38–40% high proteins, 23–23% carbs, and an extensive amount of polyunsaturated fatty acids. It makes up 25% of the world's production of edible oil (Jaybhay *et al.*, 2021). It also has a good amount of minerals and vitamins, including the B complex and tocopherol. (Chunmei *et al.*, 2010) Furthermore, soybean seed oil has a high content of unsaturated and necessary fatty acids and is cholesterol-free. Soybean oil also plays a significant role in diabetes management, dieting, and cancer disease prevention. (Fabiya, 2006 and Agwu *et al.*, 2009). Because it contains a lot of isoflavones, it helps protect against HIV, cancer, and heart disease.

Soybean grows well in different regions of the world, particularly in the tropical to the mid temperate zones. With a global production of 333.67 million tons, it occupies 120.30 million hectares. (FAO, 2021) Soybeans are grown on 0.051 million hectares of land in Bangladesh, producing 0.091 million tons of output (BBS, 2019). Bangladesh's average soybean yield (1.2tha^{-1}) is lower than the global average (BARI, 2007). Soybean is now grown extensively worldwide, including in Bangladesh, where it holds significant agricultural and economic importance. Due to favorable conditions, Bangladesh's soybean farming is centered in areas like Rangpur, Dinajpur, and Rajshahi. Bangladesh has experienced an increase in soybean production in recent years as a result of rising consumer demand for its adaptable products and potential of ensuring food security and agricultural diversification. Soybean demand in the year 2022 was 2.4 million MT but the total production in year 2022-2023 was 0.145 million MT. The gap between consumption and production is 2.25 million MT. Due to population expansion, urbanization, and evolving dietary habits, Bangladesh's demand for soybeans and their products including oil and meal is rising extensively. (FAO, 2021). Bangladesh imports 1.8 million tons of soybean cooking oil and over

25.51 million tons of soybean meal annually, at a cost of over 1.5 billion USD each US dollars annually (Quaiyum *et al.*, 2015). For Bangladeshis, particularly the poor who cannot afford pricey animal protein sources, soybeans are an excellent source of protein. A valuable element in animal feed formulations is soybean meal, which is a byproduct of the extraction of soybean oil. It plays an important role in the diets of many livestock species, greatly influencing the animals' development, well-being, and production (Hartman *et al.*, 2011). It provides vital nutrients and supports animal growth and productivity, and it is widely utilized in the poultry, livestock, and aquaculture industries. It promotes effective food use, improves physical condition, and supports the growth of muscle. (Rahman *et al.*, 2020). For dairy cows and beef cattle in particular, soybean meal is an important source of protein supplementation in their diets. Because it has a high protein and energy content, it increases milk production and growth rates. Essential amino acids found in soybean meal are vital for animal growth, muscle development, and general health. Animal feeds and the majority of manufactured meals mostly use fat-free soybean meal as an inexpensive source of protein. (Nira *et al.*, 2020). Assuring high-quality nutrition while lowering feed formulation costs is one of the major economic benefits of using soybean meal in animal feed. This financial effectiveness promotes the profitability of livestock farming by bringing down the cost of animal production. In Bangladesh, soybean is called the Golden bean. (Fahmina *et al.*, 2013) Bangladesh's soybean industry has potential, but it also confronts a number of obstacles, including a lack of access to better varieties, pressure from pests and diseases, insufficient mechanization, and losses after harvest.

An essential secondary nutrient, sulphur (S) assists in the synthesis of vitamins, chlorophyll, and essential amino acids, including methionine, cysteine, and cystine. (thiamine and biotin). Due to little or no S addition to the soil, sulphur deficits in crops have become more common, as more S-free fertilizers are being used, more S is being removed from the soil by crops with higher yields, and more intensive farming methods. It is also important for many other metabolic activities, including as the synthesis of chlorophyll, the activation of enzymes, and nitrogen metabolism. Sufficient availability of sulphur encourages rapid vegetative growth and complete plant development. (Kamran *et al.*, 2021). Since soybeans are sulfur-loving plants, they require more sulfur than many other crops do for healthy growth and productivity, just like other oilseed crops require. Sulphur is involved in the production of oil in soybean seeds, it is used as well as a soil amendment. (Manoj *et al.*, 2023). As sulfur (S) is an essential macro nutrient, using sulfur as a soil amendment to lower soil pH is more practical in the field as it is less expensive and has a longer-lasting impact because of its slow oxidation processes (Neilsen *et al.*, 1993).

Phosphorus, as a major element is necessary for plants to flourish throughout all phases of their life cycles, but it's particularly significant in the early stages of development. (Khanam *et al.* 2016). The plant cannot develop to its full capacity or meet its needs for phosphorus, one of the main necessary elements finish the process of regular reproduction. Phosphorus is considered to be a significant and necessary macro nutrient that all plants need since it helps with numerous metabolic processes, such as cell respiration, division, synthesis of new tissues, photosynthesis, nucleic acid synthesis, glucose synthesis, N fixation, and phospholipid synthesis (Thavarajah *et al.*, 2010). Phosphorus shortage can limit nodulation by soybean plants. For soybeans to grow and develop, Sulphur is a necessary nutrient. In Bangladesh few information is available on the growth and yield of soybean and nutritional quality of soybean seed as livestock feed as influenced by sulphur and phosphorous application. Our study underscores the significance of strategic sulphur and phosphorus fertilization in strengthening soybean growth and nutritional quality for livestock feed production.

Hence, this research work was undertaken with the following objectives

1. To investigate the effect of sulphur and phosphorus fertilizer application on the growth parameters and yield of soybean in south west Bangladesh
2. To measure the influence of phosphorus and sulphur fertilizer on the nutritional quality of soybean seed for livestock feed.

CHAPTER II

LITERATURE REVIEW

The soybean (*Glycine max*) is a cornerstone of modern agriculture, valued not only for its versatility but also for its exceptional nutritional profile. Because of the crop's inadequate production, it is essential to enhance the cultivation processes for soybeans. In Bangladesh, limited information is available on the impact of S and P fertilizers on soybean cultivation, with a specific focus on their effects on growth parameters, yield outcomes, and the nutritional quality of soybeans as livestock feed. Yet under the following areas, an attempt has been made to evaluate some of the domestic and international literature that is pertinent to the current study. The influence of sulfur (S) and phosphorus (P) fertilizers on the growth, yield, and nutritional quality of soybean as livestock feed has been extensively studied, given the crop's significance in agricultural systems and animal nutrition

2.1 Morphological Characteristics

The morphological traits of soybean (*Glycine max*) are diverse and essential to its identification, production, and use. Features of the roots, stems, leaves, flowers, pods, and seeds are among these attributes.

Growth Habit

Soybeans grow in an upright or semi-erect manner, reaching heights of 0.5 to 1.5 meters. Determinate or unpredictable development patterns can also be seen in the plant. While indeterminate varieties keep growing vegetatively even after flowering and pod formation, determined varieties stop growing once flowering starts.

Stem

The stem of the soybean plant is typically erect and can vary in height from 30 cm to over 2 meters, depending on the cultivar and growing conditions (Probst & Judd, 1973). The stem can be green or reddish-brown in color, and it is typically pubescent (covered with fine hairs).

Leaves

The leaves of soybean plants are trifoliate, with three leaflets on each leaflet. Usually oval to lanceolate, the leaflets have widths of 2 to 7 cm and lengths of 5 to 15 cm. The underside of the leaflets is lighter and somewhat hairy, but the upper surface is smooth and dark green.

Flowers

The little, usually 6-7 mm diameter blooms of soybeans are either white, pink, or purple in hue. They grow on the leaf axils and are grouped in clusters known as racemes (Hymowitz & Singh, 1987). Since soybean flowers include both male (stamens) and female (pistil) reproductive components inside one bloom, they are self-pollinating (Palmer *et al.*, 2004).

Seeds

The normal form of soybean seeds ranges from spherical to oval, with diameters between 5- and 11-mm. Seed coats come in a variety of colors, such as bicolored patterns, yellow, green, brown, and black. The hilum, the tip where the seeds connect to the pod, is conspicuous and can have different colors. Since soybean seeds are high in oil and protein, they are excellent for feeding livestock as well as for human consumption (Wilson, 2008).

2.2 Physiological Characteristics of Soybean

The physiological traits of soybeans (*Glycine max*) are vital to their growth, development, and production. These traits affect how well it performs as a crop overall and how well it adapts to different settings.

Photosynthesis

Under stressful circumstances, photorespiration can lower photosynthetic efficiency in C3 plants, such as soybeans (Jordan & Ogren, 1984).

Nitrogen Fixation

Since Rhizobium bacteria and soybeans coexist symbiotically in their root nodules, soybeans have the rare capacity to fix atmospheric nitrogen. Increased soil fertility and decreased reliance on nitrogen fertilizers are the results of this process, which supplies a large amount of the nitrogen needed for soybean development. Soil pH, temperature, and the availability of suitable Rhizobium strains are some of the elements that can affect how well nitrogen fixation proceeds.

Water Use Efficiency

Soybeans have a modest water use efficiency (WUE), or the ratio of biomass produced to water utilized (Sinclair *et al.*, 1984). Breeding and agronomic techniques, such as maximizing planting density and timing irrigation, can enhance WUE in soybeans.

Growth Stages

Vegetative (V) and reproductive (R) stages are the two primary stages of soybean growth and development. While blooming, pod formation, and seed development are all included in the reproductive stage, the vegetative stage consists of the growth of leaves, stems, and roots.

Temperature Response

Due of their extreme temperature sensitivity, soybeans grow best around 25 to 30 degrees Celsius

(Boote *et al.*, 2018). A number of physiological processes, like as germination, photosynthesis, and pod set, can be negatively impacted by temperatures that are above or below this range. High temperatures can cause flower and pod abortion, which can result in poorer yields, especially during the blooming and pod-filling periods (Westgate *et al.*, 1997).

Nutrient uptake

For maximum growth, soybeans need a balanced supply of vital elements. Essential macronutrients include potassium (K), phosphorus (P), and nitrogen (N). While potassium and phosphorus need to be taken up from the soil, nitrogen is mostly provided via biological nitrogen fixing., micronutrients such as iron (Fe), manganese (Mn), and zinc (Zn) are essential for a number of physiological functions. (Bender *et al.* 2015)

2.3 Production Characteristics of soybean Seed Yield

The most important aspect of soybean production is seed yield, which is determined by a variety of variables including the seed size, quantity, seeds per pod and number of pods per plant (Specht *et al.*, 1999).

Genetic Improvement

Breeding programs have greatly increased the potential output of soybeans by improving genetics. According to Specht *et al.* (1999), modern cultivars are cultivated for characteristics including enhanced fertilizer usage efficiency, drought tolerance, and disease resistance.

2.4 Agronomic Practices

Row Spacing

Light interception, canopy growth, and yield are all impacted by row spacing. Narrow row spacing typically results in faster canopy closure, less weed pressure, and higher photosynthetic efficiency. (De Bruin *et al.*, 2008)

Harvesting Time

The timing of soybean (*Glycine max*) harvest is a critical factor that affects yield, seed quality, and overall profitability. Understanding the optimal time for harvesting can help farmers maximize their returns and maintain high-quality produce. Harvesting at the optimal time ensures maximum yield and seed quality, which are essential for profitability and marketability.

2.5 Post-Harvest Handling Drying:

To stop mold from growing and preserve the integrity of the seeds while they are being stored, proper drying methods are important. When natural drying is not adequate, artificial drying techniques such as hot air dryers can be used (Carter *et al.*, 2004).

Storage

To maintain the quality of harvested soybeans, proper storage conditions are essential. To avoid

moisture buildup and insect infestation, the storage area should be dry, cold, and well-ventilated (Carter *et al.*, 2004). In order to avoid mold growth and seed deterioration, storage facilities should maintain low humidity levels.

2.6 Distribution of Soybean in Bangladesh

The soybean (*Glycine max* L. Merrill), a legume that is native to East Asia, is extensively grown for its edible and adaptable bean. It is a member of the annual plant family. The UN Food and Agricultural Organization (FAO) classified soybeans as an oilseed rather than a pulse. (Saha *et al.*, 2022) The Mississippi valley has a significant amount of the soybean land in the central United States, extending from Central Minnesota (45°N) to the Gulf of Mexico (30°N). (Singh *et al.*, 2020).

The United States and Brazil have surpassed China in terms of soybean production in recent times (FAO, 2017). Nearly 4,000 years ago, China was the place where soybean was domesticated (Kamshybayeva *et al.*, 2017). Bangladesh initially received soybeans in 1942, but no serious attempts were made to market or conduct studies on the commodity until 1960–1961. In 1961, the Bangladesh Agricultural Research Institute (BARI) division chose the Pelican and Barnali varieties of soybeans to boost productivity on fallow land during the kharif-2 season. (Kh Shafiqul Islam *et al.*, 2022). The Mennonite Central Committee (MCC) brought soybeans back to Bangladesh in 1972–1973. The "Bangladesh Coordinated Soybean Research Project" was started in 1975 by the Bangladesh Agricultural Research Council (BARE), in partnership with BARI, Bangladesh Agricultural University (BAU), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Council of Science and Industrial Research (BCSIR), and MCC, to explore the potential of soybean as a food crop. This resulted in the introduction of the Bragg and Davis soybean cultivars in 1981 (MC, 1987)

2.7 Feeding System

Soybeans and their by-products play a critical role in livestock feeding systems, offering high-quality protein and energy. Proper processing and careful feed formulation are essential to maximize the benefits of soybeans while mitigating the effects of anti-nutritional factors.

Soybean Meal

For animal feed, soybeans are most frequently utilized as soybean meal. It is a residue left over from the extraction of soybean oil and is often offered in two formats: solvent-extracted and mechanically-extracted (Karr-Lilienthal *et al.*, 2005). Whereas mechanically extracted soybean meal has a little lower protein level but retains more oil, solvent-extracted soybean meal has a protein content of 44–48% (Karr-Lilienthal *et al.*, 2005). Depending on the animal and its unique nutritional needs, different livestock species have different percentages of soybean meal in their diets. For instance, pig and poultry diets may contain up to 30% soybean meal, but dairy cow diets may contain up to 20% of the same (NRC, 1998; NRC, 2001). These inclusion rates guarantee that animals get enough protein without

compromising other essential nutrients.

Whole Soybean

whole soybeans may also be utilized in cattle feeding systems, but they need to be appropriately heat-treated to eliminate anti-nutritional elements such trypsin inhibitors (Parsons *et al.*, 1991). Heat treatment increases the nutritional content and digestibility of soybeans, ensuring their safety for use in animal feeds (Liener, 2000). For ruminants (cattle, sheep, and goats), whole soybeans are especially advantageous since their digestive tracts can efficiently employ the high fat content for energy (NRC, 2001). To prevent adverse effects on the digestion of fiber and rumen function, the inclusion rate should be carefully regulated.

Soybean Hulls

Ruminant diets may contain soybean hulls, a by-product of soybean processing that is high in fiber. They are a rich source of easily digested fiber and can support healthy rumen function. To prevent consuming too much fiber, their inclusion level should be watched.

2.8 Feed Formulation Balanced Diets:

The nutritional requirements of the individual livestock species must be carefully taken into account when creating balanced diets that incorporate soybean products (NRC, 1998). In order to improve feed formulations and guarantee that all necessary nutrients are supplied in the proper amounts, nutritional advisers frequently employ computerized tools (NRC, 2012).

Supplementation

To fulfill the unique nutritional needs of cattle, extra amino acids, vitamins, and minerals are occasionally added to soybean products. The optimum development and health outcomes for animals are guaranteed by this supplementation.

2.9 Nutritional Quality of Soybean as Livestock Feed

According to research by Ali *et al.* (2020), there is an expectation that the human population will reach 9 billion by 2050, placing significant strain on the animal production industry to meet food demands. As nutrition had a dynamic role in milk production, animal health, disease resistance, excellent body score, and proper growth of animals to improve the economics of this sector, it is an essential component of the animal production sector (Kambara *et al.*, 1993; Wallace *et al.*, 1995). Since the production of milk and meat in the animal production industry depends largely on soybeans, as they are an extremely rich source of protein. Soybean meal was recommended as the best source of protein by Fan *et al.* (1995). It provides around 480 g/kg of high-quality dry matter protein (Yamka *et al.*, 2003). In recent years, feeding soybean meals and their byproducts to lactating animals is quite

contemporary. Soybean oil supplementation is an efficient way to lower the amount of saturated fat in dairy cow diets while increasing the amount of monounsaturated fat in milk (Park *et al.*, 2020). Soybean meal is a perfect source of protein for every type of the poultry industry, with the chicken meat sector being one of the main consumers of 50% of all soybean meal utilized in animal industries

Protein Content and Amino Acid Profile

Soybeans' efficiency as animal feed is mostly determined by their protein content and amino acid composition. In recent years, its utilization is quite acceptable in every aspect of the animal production industry because of its unique qualities and high nutritional content. (Castro *et al.*, 2007) Since soybeans are the highest-quality vegetable protein source, they are becoming more and more popular in animal diets as animal proteins are being eliminated (Banaszkiewicz, 2011). Of the legume seeds, soybean meal has the highest level of crude protein and the best amino acid profile, with only 6% crude fiber (Dei, 2011). As soybeans have the largest crude protein content (44.1%) of any legume according to crude protein analysis and since they increase milk, they are the ideal legume for feeding animals and serving as a bypass protein source for dairy cows (Osti *et al.* 2013). Soybean meal is a perfect source of protein for every type of the poultry industry, with the chicken meat sector being one of the main consumers of 50% of all soybean meal utilized in animal industries (Willis, 2003) When given to non-ruminant animals, properly processed vegetable proteins like SBM may promote growth, according to Araba and Dale (1990). According to a number of scientists (Mielke and Schingoethe, 1981; Rafalowski and Park, 1982; Anderson and Wolf, 1984; DePeters *et al.*, 1985; Drackley and Schingoethe, 1986), oilseed meals like soybean, cottonseed, and sunflower meal represent a significant source of fat and amino acids for animal production (Ipharraguerre and Clark, 2005) The nutritional profile of soybean meal is improved by sulfur fertilization, which is well recognized for its ability to increase the synthesis of Sulphur containing amino acids like cysteine and methionine, which are essential for protein structure and function (Zhao *et al.*, 1999). Sulfur can also raise soybean seeds' total protein content, which raises their value as animal feed (Grant *et al.*, 2001).

Crude Fiber

A vital component of animal digestion, crude fiber is the indigestible part of plant material that is mostly composed of cellulose and lignin. The amount of crude fiber in soybeans varies from 5 to 6%, depending on the type (Medic *et al.* 2014). To keep livestock's digestive systems healthy, they need crude fiber. It promotes peristalsis and prevents constipation, which helps the gastrointestinal system work properly.

Carbohydrates

Carbohydrates, such as NSP and oligosaccharides, are abundant in soybeans (Zdunczyk *et al.*, 2011). About 35% of soybean seeds and 40% of SBM are composed of carbohydrates. A tiny portion, referred to as pectic polysaccharides, are structural polysaccharides, while the other half is composed of non-structural oligosaccharides (Karr-Lilienthal *et al.*, 2005). NSP, which have anti-nutritive properties, make up the majority of the seed's fiber content (Choct *et al.*, 2010).

Fatty Acids

Omega-3 and omega-6 linoleic and alpha-linolenic acids are among the many important fatty acids that may be found in soybean oil (Ensminger *et al.*, 1990). These fats are necessary to keep immune systems functioning, preserve the integrity of cell membranes, and enhance the quality of animal products like milk and meat (NRC, 2001).

Dry Matter (DM), Ether Extract (EE), and Ash Content

Dry matter content of soybeans ranges from 87% to 93%, depending on the variety and cultivation parameters (Wilcox & Shibles, 2001). Soybeans are an effective source of nutrition for animals because of their high dry matter content, which suggests a significant concentration of nutrients.

With an ether extract concentration ranging from 18% to 22%, soybeans are an oily food (Bellaloui *et al.*, 2015). Essential fatty acids, which are critical for the growth and well-being of cattle, are also provided by this high oil content in addition to calories (Grieshop *et al.*, 2003). The significant ether extract content provides a rich energy source, essential for high-producing animals such as dairy cows and broilers.

Ash content represents the total mineral content in soybeans after complete combustion of organic matter. The ash content of soybeans ranges from 4.5% to 5.5% (NRC, 2012). The elements included in the ash content are essential for maintaining bone health, metabolic functions, and general vigor.

2.10 Impact of Soybean on Animal Health and Productivity

Growth Performance

It has been demonstrated that adding soybean meal to the diets of many livestock species, such as pigs, cattle, and poultry, increases growth rates, feed efficiency, and overall production (Dei, 2011). Soybean meal's high protein content and well-balanced amino acid composition promote healthy muscle building (NRC, 1998).

Milk Production

Soybean meal is an essential protein supplement for dairy cattle that enhances milk protein content and increases milk production. Soybean products can improve lactation efficiency and total milk production in dairy diets.

Meat Quality

Meat quality can also be improved by feeding cattle soybeans and soybean meal. Better marbling, softness, and taste in meat products are a result of soybeans' essential fatty acid content (Ensminger *et al.*, 1990). Furthermore, lean muscle development and carcass quality are supported by the balanced amino acid profile of soybean meal (Cromwell, 1999).



2.11 Phosphorus and Sulphur Role in Soybean

Phosphorous role

Sufficient phosphorus is necessary for soybean plants to have strong root systems that improve fertilizer and water absorption (Singh *et al.*, 2011). In addition, phosphorus is necessary for the synthesis of ATP, the cell's energy currency, which is necessary for a number of physiological functions in soybeans (Marschner, 2012). A sufficient supply of phosphorus promotes root growth, which raises the intake of nutrients and water (Fageria *et al.*, 2017). In soybeans, phosphorus deficit can cause lower seed output, delayed maturation, and stunted growth (Grant *et al.*, 2001). It has been demonstrated that sufficient phosphorus fertilization greatly raises soybean yield and enhances seed quality by increasing oil and protein content (Fageria *et al.*, 2017; Singh *et al.*, 2011).

Sulphur's Role

Sulfur is necessary for soybeans to produce sulfur-containing amino acids, such as cysteine and methionine, which are crucial for protein synthesis and general plant health (Bellaloui *et al.*, 2014). Nitrogen fixation, a crucial step for leguminous plants like soybeans, also requires sulfur (Marschner, 2012). Reduced growth, poorer yield, and chlorosis (yellowing) of the younger leaves are some signs of sulfur deficiency. To increase soybean production and enhance the nutritional quality of the seeds especially the protein content adequate sulfur feeding is required (Bellaloui *et al.*, 2014).

Combined Impact of Sulfur and Phosphorus

Research has shown that phosphorus and sulfur have both antagonistic and synergistic relationships, but how they interact depends on the crop type and rate of application (Chaurasia *et al.*, 2009; Dwivedi and Bapat, 1998). Synergistic effects on soybean growth and production have been demonstrated when phosphorus and sulfur fertilizers are applied together (Bender *et al.*, 2015). Additionally, the improved nutritional quality of soybean seeds increases their value as animal feed when combined with sulfur and phosphorus-integrated nutrient management strategies.

2.12 Growth, Yield and Yield Attributing Characters

Effect of Phosphorous

The impact of three P levels (30, 60, and 90 kg ha⁻¹) and three P sources was investigated in a field experiment carried out by Sharma et al. in 2002 in Rajasthan, India during the rainy seasons of 1997 and 1998. The yield, dry matter, and yield components generated by P at 60 kg were superior to those at 30 kg ha⁻¹. Kumar *et al.* 2017 conducted a field experiment in Srinagar, India during two consecutive kharif seasons of 2010 and 2011 to determine the effect of 4 P levels (0, 30, 60 and 90 kg ha⁻¹) and P at 90 kg ha⁻¹ caused significant increases in plant growth, seed yield, biological yield and harvest index of soybean plants.

According to Akter et al., 2013 A field study was carried out from December 2008 to April 2009 at the Sher-e-Bangla Agricultural University Farm in Dhaka, Bangladesh, to assess the impact of 4 P (0, 15, 30, 50 kg P₂O₅ ha⁻¹). These included a large increase in plant height, the number of primary branches per plant, the number of leaves per plant, and the stover output, which reached 50 kg P ha⁻¹. In 2000, Bothe et al., assesses the impact of P fertilizer (0, 25, 50, and 75 kg P₂O₅ ha⁻¹). The effects of spacing (30 x 10, 20 x 10, and 30 x 5 cm) and P-solubilizers on a soybean-fenugreek cropping system's yield and yield components were assessed in 1995, Pune, Maharashtra, India. As the amount of P fertilizer rose, all yield metrics went up. P at 25 kg ha⁻¹ achieved the maximum seed yield (42.83 q ha⁻¹), whereas P at 75 kg ha⁻¹ reported the highest values for plant height (71.20 cm), dry matter per plant (57.46 g), and straw production (49.50 q ha⁻¹). Sundari A. (2003) carried out field studies in the Periyaru Vigiai Command region (Tamil Nadu, India) during the kharif season to investigate the effects of phosphorus levels (0, 40, 80, and 120 kg ha⁻¹) on soybean development. When 80 kg P₂O₅ ha⁻¹ was applied, the growth metrics were higher than with other treatments.

A field experiment was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka, Bangladesh during December 2013 to April 2014 to evaluate the effect of phosphorus (P₀: 0 kg TSP ha⁻¹, P₁: 100 kg TSP ha⁻¹, P₂: 175 kg TSP ha⁻¹, P₃: 250 kg TSP ha⁻¹) and potassium (K₀: 0 kg Mop, K₁: 60 kg Mop ha⁻¹, K₂: 120 kg Mop ha⁻¹, K₃: 180 kg MoP ha⁻¹), and their combinations on growth and yield of soybean Khanam *et al.* (2016) reported that the growth attributes and grain yield of

soybean significantly increased with the application of the fertilizers. The grain yield and maximum number of pods per plant of soybean (51.14) was recorded from 175 kg ha⁻¹ TSP. The findings are consistent with those of Singh and Bajpai (1990), who observed that the number of pods per plant rose as the phosphorus rate increased up to a certain point before declining.

Effect of Sulphur

A field experiment was carried out by Mohanti *et al.* (2004) in Raipur, Chhattisgarh, India during the kharif 2003–2004 to assess the effects of various S (0, 10, 20, and 30 kg ha⁻¹) and B (0 and 0.002% at pre-flowering or pre-podding) levels on the soybean variety JS-335. Data on test weight, dry matter accumulation, plant height, and number of branches per plant were recorded. both seed yield and harvest index. The greatest values for these parameters were reported by S at 30 kg ha⁻¹. B's relationship with S had no appreciable impact. S at 20 kg ha⁻¹ and S at 30 kg/ha had the highest net realization per investment.

A field experiment was carried out in Ludhiana, Punjab, India, by Manchanda *et al.* in 2006. In order to determine the effects of S fertilizer (0.7.5, 15.0, and 30 kg S ha⁻¹ as gypsum) on the loamy sand soil low in accessible S (7.37 mg kg⁻¹soil) during 2003–2004 crop production and nutritional status in a soybean (cv. SL 295)-wheat (cv. PBW 343) hybrid system. Applying 7.5 and 15.0 kg S ha⁻¹, respectively, resulted in a 23.1% and 30.5% increase in soybean grain production above the control. With the administration of S, these crops' overall biological yield also rose noticeably. Both crops harvest indexes, however, were not considerably impacted.

Sangale *et al.* (2004) studied the effects of S fertilizer sources (single super phosphate, elemental S, and gypsum) and amounts (0, 10 and 20 kg ha⁻¹) on the quality, yield, and S content of seeds in a field experiment performed during kharif 2003–04. uptake of soybean cv. JS 335 planted in Maharashtra's Marathwada area on deep black soil of India. Elements S was administered 15 days before to planting, whereas gypsum and single super phosphate were applied at the time of sowing. Combining Yield was maximum at 20 kg ha for S. Gokhale *et al.* (2005) carried up a field experiment in Maharashtra, India, during Kharif 2002–2004, to investigate the effects of various sulfur (S) levels (0, 10, 20, 30, 40, and 50 kg ha) on soybean (cv. MACS 124). Applying higher S levels—up to 30 kg ha⁻¹—increased seed yields compared to the control. "Thus, 30 kg S ha⁻¹ produced the maximum soybean yield of 25.1 q ha. The yields were marginally lowered by treatments with 40 and 50 kg S ha⁻¹ because the soil under investigation had a moderately low S content (9.6 mg ha⁻¹), which indicated responses to lower S levels. Mohan and Sharma (1991) observed that S @ 75 kg ha⁻¹ significantly increased primary and secondary branches plant. Sulphur @ 50 kg ha⁻¹ increased the plant height significantly.

Effect of sulphur and phosphorus interaction

Limited research has been done on the interaction between phosphorus and sulphur. But some of the relevant literature for this research is included below

(Kumawat *et al.*, 2004); (Kumar and Singh, 1980) demonstrated a synergistic impact of applied P and

S for soybean. (Kumar and Singh, 1980) found that soybeans provided a good P and S balance for generating higher yield. It has been demonstrated by (Aulakh et al., 1990) and (Singh et al., 1995) that the P and S interaction's nature is dependent upon their application rates.

In 1999, Tomar *et al.* carried out a field study in Madhya Pradesh during the kharif season India conducted research on the effects of rhizobium (*Rhizobium japonicum* / *Bradyrhizobium japonicum*) inoculation and P and S fertilizers on growth yield and soybean quality. The treatments included 0, 30, and 60 kg of P ha⁻¹; 0, 20, and 40 kg of S ha⁻¹; and both an inoculation with and without *R. japonicum*. Plant height, leaf area index, main root length, number of root nodules per plant, dry matter accumulation, number of pods per plant, number of seeds per pod, test weight, yield of seeds and straw, and protein and oil contents all increased with each treatment.

Thus, it can be assumed from the overview of the studies mentioned above that phosphorus and sulfur impact the growth and production of soybeans and other oil crops. The ideal and sufficient amount of phosphorus and sulfur should be applied are therefore essential to reaching increased soybean growth and production because phosphorus and sulfur fertilizer management are still deficient in our country.

CHAPTER III

MATERIALS AND METHOD

3.1 Site of the experiment

The experiment was conducted at Professor Dr. Purnendu Gain Field Laboratory of Agrotechnology Discipline, Khulna University, Khulna. The experimental location is situated within the agroecological zone of the Ganges Tidal Flood Plain (AEZ 13) positioned at North 22.80° latitude and East 89.53° longitude

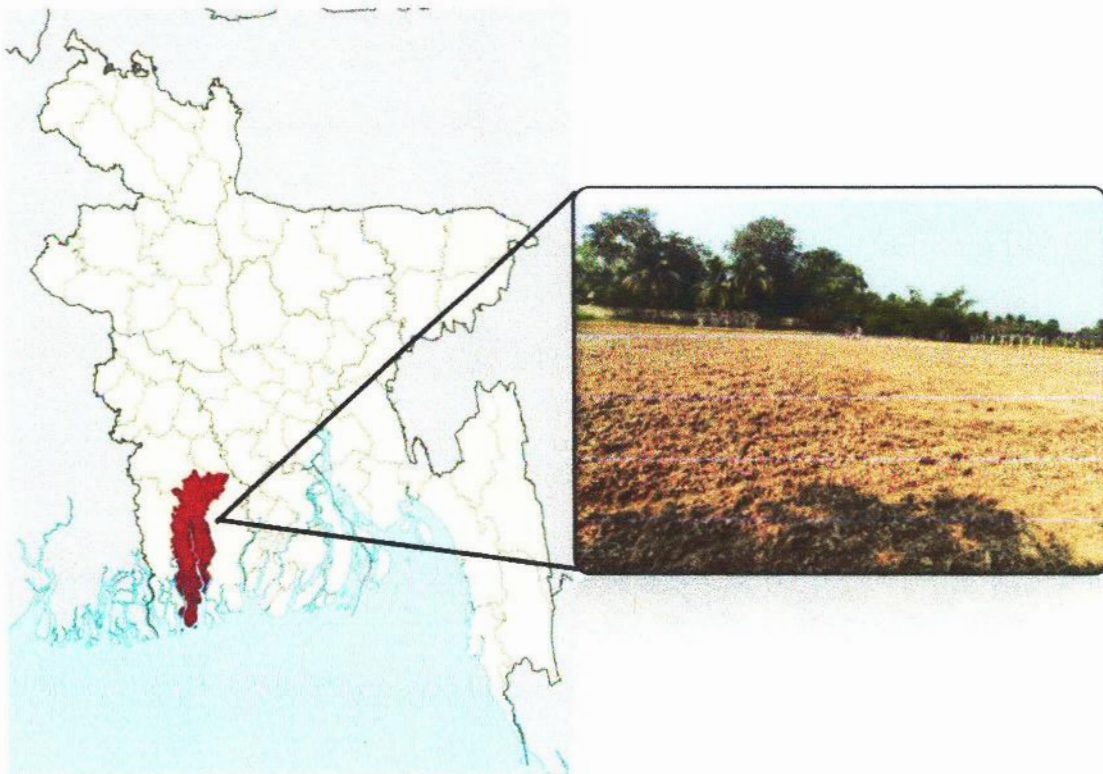


Figure 1 Experimental location

3.2 Climatic condition

The climate of the research site was characterized by relatively high temperatures, substantial rainfall, and frequent strong winds during kharif season (April-September), and low temperatures and low humidity during the Rabi season (October-March)

3.3 Description of soil

Soil of that area are mostly calcareous to non-calcareous, silty clay loam to clay in texture, grey to

dark grey in color and low saline affected. The pH level is 8.1 that means slight to moderate alkaline. Details of some soil properties are given in the table below

Table 1: Some physical and chemical properties of soil in the experimental area.

Parameters	Value	Status
Soil pH	8.10	Moderate
EC (dSm ⁻¹)	4.40	Low
Organic matter	1.85	Medium
Nitrogen (%)	0.11	Very Low
Phosphorous (µg g ⁻¹)	6.81	Very Low
Potassium (meq 100 g ⁻¹)	0.41	High
Sulphur (µg g ⁻¹)	40.2	Very High
Zinc (µg g ⁻¹)	0.29	Very High
Boron (µg g ⁻¹)	1.22	Very High
Shaikh <i>et al.</i> , (2023)		

3.4 Description of the soybean variety

BINA Soybean-5, a high yielding variety of soybean was used as the test crop in this experiment. BINA-Soybean 5 is an improved soybean variety developed by the Bangladesh Institute of Nuclear Agriculture (BINA). Life cycle of this variety ranges from 95 to 115 days. The variety is resistant to yellow mosaic virus. This variety is tolerant to 8dS/m degree salinity. For planting, seeds that had been plummy, robust, well-matured, and wealthy were selected

3.5 Preparation of the field

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 Treatments

Fertilizer treatments consisted of 3 levels of sulphur and 3 levels of phosphorous. There were 9 treatment combinations. The rates of P and S and their treatment combinations are shown below:

Rates of Sulphur (3)

$S_0 = 0 \text{ kg S ha}^{-1}$

$S_1 = 6.51 \text{ kg S ha}^{-1}$ (Recommended dose (35kg/ha Gypsum))

$S_2 = 9.76 \text{ kg S ha}^{-1}$ (50% more than recommended dose (53kg/ha Gypsum))

Rates of Phosphorus (3):

$P_0 = 0 \text{ kg P ha}^{-1}$

$P_1 = 14 \text{ kg P ha}^{-1}$ (Recommended dose of P (70kg/ha TSP))

$P_2 = 21 \text{ kg P ha}^{-1}$ (50% more than recommended dose (105kg/ha TSP))

3.7 Layout of the experiment

The experiment was laid out in a randomized complete block design with three replications. The field measurement is 150m^2 . The line-to-line distance were 30cm. The total numbers of plots were 27. each measuring $3\text{m} \times 2\text{m}$ (6m^2). The treatment combination of the experiment was assigned at random into 9 plots of each at 3 replications. The adjacent block and neighboring plots were separated by 1.0 m and 0.5m, respectively. The layout of the experiment is presented in Table below

Table 2: Layout of the experiment

Treatment		Replication		
Sulphur	Phosphorous	R ₁	R ₂	R ₃
S ₀	P ₀	R ₁ S ₂ P ₁	R ₂ S ₂ P ₂	R ₃ S ₀ P ₀
S ₁	P ₁	R ₁ S ₀ P ₂	R ₂ S ₂ P ₀	R ₃ S ₂ P ₁
S ₂	P ₂	R ₁ S ₀ P ₀	R ₂ S ₁ P ₀	R ₃ S ₁ P ₂
		R ₁ S ₂ P ₂	R ₂ S ₀ P ₂	R ₃ S ₁ P ₀
		R ₁ S ₁ P ₂	R ₂ S ₀ P ₁	R ₃ S ₂ P ₀
		R ₁ S ₂ P ₀	R ₂ S ₀ P ₀	R ₃ S ₂ P ₂
		R ₁ S ₁ P ₁	R ₂ S ₁ P ₁	R ₃ S ₀ P ₁
		R ₁ S ₁ P ₀	R ₂ S ₁ P ₂	R ₃ S ₀ P ₂
		R ₁ S ₀ P ₁	R ₂ S ₂ P ₁	R ₃ S ₁ P ₁

3.8 Application of Fertilizer

Fertilizer was applied at the rate of 62 kg/ha urea, 173kg/ha TSP, 99 kg/ha MoP and 87 kg gypsum per hectare. All the urea, TSP, MoP and gypsum were applied before final land preparation in 150 m² field. Urea- 25 kg/acre, Muriate of Potash – 40kg/acre (Recommended by BINA)

3.9 Seed sowing

Soybean seeds were sown on the 11 November 2023 in lines following the recommended line to line distance of 30 with continuous fine sowing method.

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 3 December, 2023.

3.11 Irrigation

Irrigation was given at three times. The first irrigation was given in the field on November 21, 2023 at eleven days after sowing through irrigation channel. Second irrigation was given in the field on December 21, 2023 at 40 days after sowing (DAS) before flowering. The third irrigation was given at the stage of pod formation (70 DAS) on January 21, 2024.

3.12 Pest Management

The crop was infested with yellow mosaic virus and leaf curling virus at the seedling stage though it was moderately resistant to yellow mosaic virus. Application of Nitro and Ripcord was done. Special care was taken to protect the crop from birds especially after sowing and germination stages.

3.13 Harvesting

The crop was harvested at full maturity on 22nd February 2024. It was harvested from 1m² area at the center of the plot. The harvested crop of each individual plot was bundled separately. Grain and straw yields were recorded plot wise and the yields were expressed in g/m²

3.14 Collection of data

3.14.1 Agronomic data

Five (5) 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. Stem Diameter (mm)

3. Number of leaves per plant
4. Number of branches per plant
5. Leaf chlorophyll content index
6. Number of pods per plant
7. Pod Length (mm)
8. Number of seeds per plant
9. Number of seeds per pod
10. Hundred seed weight (g)
11. Grain yield per square meter (g/m^2)
12. Stover yield per square meter (g/m^2)
13. Biological yield per m^2 (g/m^2)
14. Harvest index (%)

3.14.2 Seed Nutritional Data

- ✓ Crude protein
- ✓ Crude fiber
- ✓ Carbohydrate
- ✓ Ether extract
- ✓ Ash
- ✓ Dry matter
- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sulphur
- ✓ Potassium
- ✓ Iron

Plant height

The plant height was measured from the ground level to the top of the plant. 5 plants were selected randomly from each plot. Plant height was measured and averaged. Plant height was measured 5 times at 45,60,75,95 DAS and at harvest.

Stem Diameter

It was done from 5 plants which were collected randomly from each plot and with the help of slide calipers stem diameter was taken.

Number of branches per plant

5 plants were selected randomly from each plot avoiding the border plants. Number of branches were counted and averaged. Number of branches per plant was measured and averaged. Plant height was measured 5 times at 45,60,75,95 DAS and at harvest

Number of leaves per plant

5 plants were selected randomly from each plot and number of leaves were counted and averaged. Number of branches per plant was measured and averaged. Plant height was measured four times at 45,60,75,95 DAS.

Leaf Chlorophyll content index

Leaf chlorophyll content was measured by SPAD chlorometer in 75(DAS) at 12.00 PM. Each middle part of the plant leaf was measured by SPAD meter. Three measurements were taken and the average chlorophyll content was recorded.

Number of pods per plant

Pods were counted from 5 plants selected randomly from each plot during harvesting. Number of pods per plant were counted and averaged.

Pod Length

The length of each pod was measured using a measuring scale from the 5 selected plants and then calculated the average value.

Number of seeds per pod

Every pod was counted from the 5 selected plants. The pod was split to count the seeds per pod.

Number of seeds per plant

Number of seeds per plant were counted and recorded of selected five plants

Hundred seed weight

Hundred seed of soybean were counted from each plot and then weighed with a balance.

Grain yield

Grains obtained from 1 m² area from the center of each unit plot was dried separately, weighed carefully and recorded.

Stover yield

Stover remained after collection of grain from 1 m² area of each individual plot was dried separately, weighed carefully and recorded.

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.

Harvest Index (%)

Harvest index, the ratio of economic (seed) yield to biological yield was estimated and expressed as percentage using the following formula

Harvest Index (HI)= Grain yield / Biological yield × 100

3.15 Preparation of Sample for Laboratory Analysis

The grain samples of different varieties of soybean were dried before grinding. After grinding, the samples were kept in polythene bags, labelled and stored for further analysis.

3.16 Proximate Analysis

The chemical composition of the grinding sample was determined as per the standard method of the Association of Analytical Chemist (AOAC, 1990).

3.17 Gross Energy Calculation

Gross energy was calculated by the following formula-

$$\text{Gross Energy} = (5.7 * \text{protein}(\text{gm})) + (9.4 * \text{fat}(\text{gm})) + (4.1 * \text{NFE}(\text{gm})) + \text{fiber})$$

3.18 Statistical method and analysis

Data were analyzed using the General Linear Model (GLM) procedure of SAS version 9.1, 1994 (SAS Institute, Inc.). DMRT was used to compare the treatment means with significance considered at $p < 0.05$.



RESULTS AND DISCUSSION

4.1 Effect of Sulphur and phosphorous on the growth parameter of soybean

4.1.1 Effect of Sulphur on the plant height of soybean

Soybean plants showed not significant variation in respect of plant height when different doses of Sulphur fertilizer were applied Table 3. Among the different sulphur doses, S_2 showed the highest plant height (40.36 cm) at harvest. The shortest plant was obtained from control condition S_0 (37.94 cm). 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 growth of soybean plant. Similar findings were also reported in groundnut (Chaubey *et al.*, 2000) and linseed (Dubey *et al.*, 1997). The result is similar to Tabatabai (1986) who reported that lack of Sulphur reduces plant height. It was further noticed that plant height of soybean increased as the level of S was increased

4.1.2 Effect of phosphorus on the plant height of soybean

Significant variation was not observed on the plant height of soybean when the field was fertilized with different doses of phosphorus at harvest. Among the different doses of phosphorus, P_2 showed the highest plant height (40.91 cm) at harvest and it was closely followed by P_1 treatment showing (39.73 cm) plant height. On the other hand, the lowest plant height (36.60 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 (21 kg P ha^{-1}). The increased plant height may be due to favorable effects of phosphorus on the vegetative growth of soybean plant. The outcomes resemble those of Bothe *et al.* (2000), who stated that the treatment of 75 kg phosphorus increased plant height at maximum value. According to Afzal *et al.* (2010), who also discovered comparable outcomes for plant height, phosphorus administration causes a gradual increase in plant height.

Table 3: Effect of S and P on plant height of soybean

Plant height (cm)					
Treatment	45(DAS)	60(DAS)	75(DAS)	95(DAS)	At Harvest
Level of Sulphur					
S ₀	18.83	27.35	30.61	34.08	37.94
S ₁	18.87	27.53	30.96	34.61	37.93
S ₂	20.07	28.27	31.84	37.47	40.36
P	0.73	0.87	0.80	0.11	0.33
Level of Phosphorous					
P ₀	17.54	25.92	29.43	33.68	36.60
P ₁	19.56	27.79	30.94	35.05	38.73
P ₂	20.73	29.44	33.04	37.43	40.91
P	0.21	0.19	0.19	0.10	0.09
CV (%)	19.30	14.10	13.08	9.99	10.09
S ₀ = 0 kg S ha ⁻¹ S ₁ = 6.51 kg S ha ⁻¹ S ₂ = 9.76 kg S ha ⁻¹ P ₀ = 0 kg P ha ⁻¹ P ₁ = 14 kg P ha ⁻¹ P ₂ = 21 kg P ha ⁻¹					

4.13 Interaction effect of S and P on the plant height of soybean

Crop responses to Sulphur and phosphorus interaction for plant height has been presented in Table 4. It can be observed that the interaction of Sulphur and phosphorus levels show non-significant effect on plant height at all growth stages and at harvest. The lowest plant height (35.56 cm) was observed in the control treatment combination (No phosphorus and No Sulphur). On the other hand, the highest plant height (44.56 cm) was recorded with S₂P₂ treatment combination which was followed by S₁P₁ (39.83 cm). Tomar *et al* (2004) also found the positive interaction effect of P and S on the plant height of soybean. The maximum plant height can result from the beneficial effects of

sulfur and phosphorus on the accumulation of growth materials and vegetative development.

Table 4. Interaction effect of S and P on the plant height of soybean

Plant height (cm)					
Interaction (S x P)	45(DAS)	60(DAS)	75(DAS)	95(DAS)	At Harvest
S₀P₀	15.83	23.80	28.40	32.60	35.56
S₀P₁	18.68	27.53	30.76	33.33	37.70
S₀P₂	22.13	30.71	32.66	36.33	40.56
S₁P₀	17.73	26.54	29.23	33.36	36.36
S₁P₁	20.00	27.68	31.43	35.43	39.83
S₁P₂	18.90	28.38	32.23	35.03	37.60
S₂P₀	19.06	27.42	30.66	35.10	37.86
S₂P₁	20.00	28.16	30.63	36.40	38.66
S₂P₂	22.16	29.22	34.22	40.93	44.56
P	0.74	0.78	0.97	0.77	0.50
CV (%)	19.30	14.10	13.08	9.99	10.09
S ₀ =0 kg S ha ⁻¹ S ₁ =6.51 kg S ha ⁻¹ S ₂ =9.76 kg S ha ⁻¹ P ₀ =0 kg P ha ⁻¹ P ₁ =14 kg P ha ⁻¹ P ₂ =21 kg P ha ⁻¹					

4.2.1 Effect of sulphur on the number of branches per plant of soybean

From table 5 it could be seen that different doses of S fertilizer showed non-significant variations in respect of number of branches from 45 to 95 DAS and also at harvest Among the different doses of Sulphur. S₂ showed the highest number of branches per plant (8.50) which was statistically similar with the S₁ treatment. On the contrary, the lowest number of branches per plant (7.77) was recorded in the S₀ treatment where no sulphur fertilizer was applied. Sulfur's beneficial effects on vegetative growth and the accumulation of growth-promoting compounds that supported the healthy growth and development of the soybean plant may be the cause of the increased number of branches

per plant. Similar outcomes were seen by Mohanti *et al.* (2004) when 30 kg S ha⁻¹ was applied. S enhanced the number of main branches per linseed plant up to 40 kg S ha⁻¹, according to Dubey *et al.* (1997). Similar findings were obtained by Ghosh *et al.* (1997).

4.2.2 Effect of phosphorus on the number of branches per plant of soybean

Phosphorus had a non-significant influence on the number of branches plant of soybean when different doses of phosphorus were applied (Table 5). The highest number of branches per plant (8.60) was recorded in P₂ which was statistically similar with the P₁ treatment. The lowest number of branches per plant (7.75) was recorded in the P₀ treatment where no phosphorus was applied. The beneficial effects of phosphorus on vegetative growth and the accumulation of growth materials that assisted in the appropriate growth and development of plants may be the cause of the increased number of branches per plant.

Table 5: Effect of S and P on the number of branches of soybean

Branch Number (No)					
Treatment	45(DAS)	60(DAS)	75(DAS)	95(DAS)	At Harvest
Level of Sulphur					
S ₀	4.91	6.41	6.97	7.42	7.77
S ₁	4.92	6.96	7.41	7.85	8.18
S ₂	5.54	7.30	7.43	7.93	8.50
P	0.16	0.29	0.72	0.67	0.48
Level of Phosphorous					
P ₀	4.78	6.33	6.87	7.25	7.75
P ₁	5.12	6.86	7.20	7.65	8.11
P ₂	5.46	7.47	7.74	8.30	8.60
P	0.20	0.14	0.40	0.25	0.37
CV (%)	14.95	17.13	18.41	16.77	15.35
S ₀ =0 kg S ha ⁻¹ S ₁ =6.51 kg S ha ⁻¹ S ₂ =9.76 kg S ha ⁻¹ P ₀ =0 kg P ha ⁻¹ P ₁ =14 kg P ha ⁻¹ P ₂ =21 kg P ha ⁻¹					

4.2.3 Interaction effect of phosphorus and sulphur on the number of branches per plant of soybean

The highest number of branches per plant (9.20) was recorded with the treatment combination of S_2P_2 treatment combinations. On the other hand, the lowest number of branches per plant (7.46) was recorded in the treatment S_0P_0 (control) combination. The highest number of primary branches plant¹ 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 6 Interaction effect of S and P on the number of branches

Branch Number (No)					
Interaction (S x P)	45(DAS)	60(DAS)	75(DAS)	95(DAS)	At Harvest
S_0P_0	4.50	5.76	6.73	7.03	7.46
S_0P_1	4.80	6.40	6.80	7.33	7.70
S_0P_2	5.43	7.06	7.40	7.90	8.16
S_1P_0	4.56	6.46	7.10	7.46	7.93
S_1P_1	5.06	6.93	7.40	7.83	8.20
S_1P_2	5.13	7.50	7.80	8.26	8.43
S_2P_0	5.30	6.76	6.80	7.26	7.86
S_2P_1	5.50	7.26	7.40	7.80	8.43
S_2P_2	5.83	7.86	8.03	8.73	9.20
P	0.96	0.99	0.99	0.99	0.98
CV (%)	14.95	17.13	18.41	16.77	15.35
$S_0=0 \text{ kg S ha}^{-1}$ $S_1=6.51 \text{ kg S ha}^{-1}$ $S_2=9.76 \text{ kg S ha}^{-1}$ $P_0=0 \text{ kg P ha}^{-1}$ $P_1=14 \text{ kg P ha}^{-1}$ $P_2=21 \text{ kg P ha}^{-1}$					

4.3.1 Effect of Sulphur on the number of leaves per plant of soybean

Among the different doses of fertilizers, recommended dose and 50% more than the recommended dose performed similarly in number of leaves that is S_2 showed the highest number of leaves per plant (11.63) which was statistically similar with S_1 . On the contrary, the lowest number of leaves per plant (9.950) was recorded in the S_0

treatment where no Sulphur fertilizer was applied. The increased number of leaves per plant 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 Gin (1990) also found similar results with the application of 60 kg S ha⁻¹.

4.3.2 Effect of phosphorus on the number of leaves per plant of soybean

Significant variation was observed in the number of leaves per plant of soybean when different doses of phosphorus were applied at 95(DAS) (Table 6). The highest number of leaves per plant (13.06) was recorded in P₂ (63 g) treatment which was statistically similar with P₁ treatment. The lowest number of leaves plant' (10.06) was recorded in the P₀ treatment where no phosphorus was applied. The increased number of leaves on the plant might be the result of phosphorus's beneficial effects on vegetative growth and the build-up of growth materials, which aided in the healthy growth and development of the soybean plant.

4.3.3 Interaction effect of phosphorus and Sulphur on the number of leaves plant of soybean

The combined effect of different doses of S and P fertilizers on the number of leaves per plant of soybean was not significant (Table 7). Leaf number per plant increased gradually to the highest at 60(DAS) and reduced later on. The highest number of leaves per plant (14.26) was recorded with the treatment combination of S₂P₂. On the other hand, the lowest number of leaves plant' (9.133) was recorded in the S₁P₀ treatment combination. The highest number of leaves plant' 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.

4.4.1 Effect of Sulphur on the leaf chlorophyll content

Different doses of Sulphur fertilizer showed highly significant variations in respect of Chlorophyll content (Table 7). Among the different doses of fertilizers, S₂ showed the highest chlorophyll content (41). On the contrary, the lowest chlorophyll content (30.14) was recorded in the S₀ treatment where no Sulphur fertilizer was applied.

Table 7: Effect of S and P on the number of leaf and chlorophyll content

Leaf Number (No) and Chlorophyll content					
Treatment	45(DAS)	60(DAS)	75(DAS)	95(DAS)	75(DAS) Chlorophyll content
Level of Sulphur					
S ₀	14.80	20.66	19.30	10.74	30.13b
S ₁	15.22	22.42	20.33	12.21	38.47a
S ₂	15.60	22.36	20.87	12.17	41.07a
P	0.62	0.66	0.72	0.21	0.00
Level of Phosphorous					
P ₀	13.90c	20.47	19.06	10.06b	36.47ab
P ₁	15.34b	22.12	20.35	12a	33.38b
P ₂	16.37a	22.85	21.078	13.06a	39.82a
P	0.023	0.53	0.59	0.01	0.04
CV (%)	11.37	19.54	20.84	16.48	13.61
S ₀ = 0 kg S ha ⁻¹ S ₁ = 6.51 kg S ha ⁻¹ S ₂ = 9.76 kg S ha ⁻¹ P ₀ = 0 kg P ha ⁻¹ P ₁ = 14 kg P ha ⁻¹ P ₂ = 21 kg P ha ⁻¹					

A column followed by similar letters is not statistically different according to Duncan's Multiple Range Test ($P \leq 0.05$)

4.4.2 Effect of Phosphorous on the leaf chlorophyll content index

Different doses of phosphorous fertilizer showed significant variations in respect of chlorophyll content index (Table 7). Among the different doses of P fertilizers, P₂ showed the highest chlorophyll content (39.82). On the contrary, the lowest chlorophyll content was recorded in the P₁ (33.34) treatment where 14 kg P ha⁻¹ Phosphorous fertilizer was applied.

4.4.3 Interaction effect of phosphorus and Sulphur on the chlorophyll content

The combined effect of different doses of S and P fertilizers on the chlorophyll content of plant of soybean was non-significant (Table 6). The highest chlorophyll content per plant (46.48) was recorded with the treatment combination of S₂P₂. On the contrary, the lowest chlorophyll content (25.80) was recorded in the S₀P₁ treatment where no Sulphur fertilizer was applied.

Table 8. Interaction effect of S and P on the number of leaf and chlorophyll content index (SPAD value)

Number of Leaves and Leaf Chlorophyll Content Index					
Interaction (S x P)	45(DAS)	60(DAS)	75(DAS)	95(DAS)	75(DAS) Chlorophyll content
S₀P₀	13.16	20.16	18.33	10.13	29.31
S₀P₁	14.83	20.70	19.30	10.80	25.80
S₀P₂	16.40	21.13	20.26	11.30	35.28
S₁P₀	13.93	20.46	19.20	9.83	39.26
S₁P₁	16.46	23.16	20.86	13.16	38.46
S₁P₂	15.26	23.63	20.93	13.63	37.69
S₂P₀	14.60	20.80	19.66	10.23	40.84
S₂P₁	14.73	22.50	20.90	12.03	35.89
S₂P₂	17.46	23.80	22.03	14.26	46.48
P	0.38	0.99	0.99	0.59	0.32
CV (%)	11.37	19.54	20.84	16.48	13.61
S ₀ = 0 kg S ha ⁻¹ S ₁ = 6.51 kg S ha ⁻¹ S ₂ = 9.76 kg S ha ⁻¹ P ₀ = 0 kg P ha ⁻¹ P ₁ = 14 kg P ha ⁻¹ P ₂ = 21 kg P ha ⁻¹					

4.5.1 Effect of sulphur on the stem diameter of soybean

Among the different doses of fertilizers, S₂ showed the highest stem diameter (3.94 mm) which was followed by S₁. The shortest stem diameter of the plant (3.65 mm) was recorded in the S₀ treatment where no phosphorus was applied. There was no significant difference among the treatments for stem diameter. (Table 9)

4.5.2 Effect of phosphorous on the stem diameter of soybean

The highest stem diameter (3.89 mm) was recorded in P₂ treatment which was statistically similar with other treatments. The shortest diameter (3.75 mm) was recorded in the P₀ treatment where no phosphorus was applied.

4.5.3 Interaction effect of phosphorus and sulphur on the stem diameter of soybean

The combined effect of different doses of P and S fertilizers on the stem diameter of soybean was non-significant (Table 9). The longest stem diameter (4.04 mm) was recorded with the

treatment combination of S_2P_2 . On the other hand, the lowest number of seeds per plant (3.41 mm) was recorded in the S_0P_2 treatment combination.

4.6.1 Effect of sulphur on the Pod length of soybean

Different doses of Sulphur fertilizer showed significant variations in respect of pod length of soybean. Among the different doses of fertilizers, S_2 showed the longest stem diameter (3.94 cm) which was statistically similar with S_1 . The shortest stem diameter of the plant (3.65 cm) was recorded in the S_0 treatment where no phosphorus was applied.

4.6.2 Effect of phosphorous on the Pod length of soybean

Significant variation was observed in the pod length of soybean when different doses of phosphorus were applied (Table 9). The longest (3.34 cm) was recorded in P_1 treatment which was statistically similar with P_2 treatment. The shortest (2.88 cm) was recorded in the P_0 treatment where no phosphorus was applied.

4.6.3 Interaction effect of phosphorus and sulphur on the Pod length of soybean

The combined effect of different doses of S and P fertilizers on the pod length of seed plant of soybean was significant (Table 9). The longest pod length of seed per plant (3.633 cm) was recorded with the treatment combination of S_2P_2 . On the other hand, the lowest number of seeds plant (2.64 cm) was recorded in the S_0P_2 treatment combination.

4.7.1 Effect of sulphur on the number of seeds per plant of soybean

Different doses of Sulphur fertilizer showed non-significant variations in respect of number of seeds per plant. Among the different doses of fertilizers, S_2 showed the highest number of seeds per plant (113) treatments. On the contrary, the lowest number of seeds per plant (89.94) was recorded in the S_0 treatment where no Sulphur fertilizer was applied. The higher number of seeds per plant might be attributed to sulfur's beneficial effects on vegetative development and the build-up of growth-promoting components, which enabled the highest quantity of soybean seeds planted. The current research supports the findings of Dubey *et al.* (1997), who found that higher sulfur levels led to a considerable rise in the number of linseed seeds per capsule. Saran and Gin (1990) also discovered comparable outcomes when 60 kg S ha^{-1} was used.

4.7.2 Effect of phosphorus on the number of seeds per plant of soybean

The highest number of seeds per plant (114.98) was recorded in P₂ (63 g) treatment. The lowest number of seeds per plant (93.19) was recorded in the P₀ treatment where no phosphorus was applied. When phosphorus levels rose to a particular point, the quantity of seeds per plant increased as well. The benefits of phosphorus on vegetative development and growth accumulation may account for the higher quantity of seeds per plant. The result confirms with the findings of Jana *et al* (1990).

4.7.3 Interaction effect of phosphorus and sulphur on the of number of seeds per plant of soybean

The highest number of seeds per plant (137.43) was recorded with the treatment combination of P₂S₂. On the other hand, the lowest number of seeds per plant (78.89) was recorded in the P₀S₀ 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' of soybean increased significantly due to combined application of increased levels of phosphorus and Sulphur. Sufficient amounts of fertilizer promoted the vegetative growth and development of soybeans, resulting in the production of the greatest number of seeds per plant.

4.8.1 Effect of sulphur on the number of pods per plants of soybean

Among the different doses of fertilizers, S₂ showed the highest number of pods per plant (34.4) treatments. On the contrary, the lowest number of seeds per plant (30) was recorded in the S treatment where no Sulphur fertilizer was applied. The increased number of pods per plant 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. Sriramachandrasekharan *et al.* (2004) made similar type of observations with the application of 30 kg S ha⁻¹ in the presence of *Bradyrhizobium* inoculation.

4.8.2 Effect of phosphorous on the number of pods per plants of soybean

The highest number of seeds per plant (35) was recorded in P₂ treatment The lowest number of seeds per plant (30) was recorded in the P₀ treatment where no phosphorus was applied.

These findings are in agreement with Reddy and Giri (1989) who reported that phosphorus application @ 20 kg P has increased the pod yield of soybean. Similar results were also found in soybean by Jana *et al.* (1990) and Singh and Bajpai (1990). The increased number of pods per plant 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.

4.8.3 Interaction effect of sulphur and phosphorus on the of number of pods per plant of soybean

Pods per plant did not affect significantly due to the interaction of S and P doses but numerically variation was observed among the treatment combination. The highest number of pods per plant (37.43) was recorded with the treatment combination of S_2P_2 . On the other hand, the lowest number of seeds per plant (27) was recorded in the P_0S_0 treatment combination (control). According to Majumdar *et al.* (2001), the quantity of pods per plant rose with the combined treatment of P and S @ 60 kg P_2O_5 ha⁻¹ and 40 kg S ha⁻¹, respectively. The maximum number of pods per plant might be attributed to the beneficial effects of both phosphorus and sulfur on soybean reproductive development and pod production.

4.9.1 Effect of sulphur on the weight of 100 seed of soybean

Among the different doses of S fertilizer, S_2 showed the highest weight of 100 seed (12.22 g). On the contrary, the lowest weight of 100 seed (11.11 g) was recorded in the S_0 treatment where no Sulphur fertilizer was applied. It's possible that sulfur's beneficial effects on vegetative growth and the buildup of elements that promote growth contributed to the increased grain weight, which in turn supported the healthy development and growth 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

4.9.2 Effect of phosphorus on the weight of 100 seed of soybean

The highest weight of 100 seed (12.55g) was recorded in P_2 treatment. The lowest weight of 100 seed (10.66g) was recorded in the P_0 treatment where no phosphorus was applied. Phosphorus has beneficial effects on plant development which may account for the increased grain weight, development and expansion of the soybean grain. The outcome is consistent with Reddy and Gajendragiri's (1989) results.

4.9.3 Interaction effect of sulphur and phosphorus on the weight of 100 seed of soybean

Numerically non-significant impact was observed in the weight of the 100 seeds due to the interaction of S and P (Table 11). The highest weight of 100 seed (13.33 g) was recorded with the treatment combination of S_2P_2 . On the other hand, the lowest weight of 100 seed (10.33g) was recorded in the P_0S_0 treatment (control treatment). The weight of 100 seed increased with increasing level of phosphorus and Sulphur up to optimum level due to the favorable effects of fertilizer on the yield attributes

4.10.1 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 9). Among the different doses of S fertilizer, S_2 showed the highest grain yield of soybean (59.46). On the contrary, the lowest weight grain yield of soybean (48.27) was recorded in the S_0 treatment where no Sulphur fertilizer was applied. The beneficial effects of sulfur on vegetative growth and the buildup of growth components that aided in the correct growth and development of the soybean may be the cause of the higher grain yield. grain. When 30 kg S ha⁻¹ was used along with

Bradyrhizohium inoculation, Sriramchandrasekharan *et al.* (2004) discovered comparable outcomes. Application of S at 20 kg ha⁻¹ produced the greatest seed yield, according to Sangale *et al.* (2004).

4.10.2 Effect of phosphorus on the seed yield of soybean

Significant variation was observed on the grain yield of soybean when different doses of phosphorus were applied (Table 9). The highest grain yield of soybean (59.46gm²) was recorded in P_2 treatment. The lowest grain yield (49.27gm²) was recorded in the P_0 treatment where no phosphorus was applied. The favorable effects of phosphorus on vegetative growth and the buildup of plant growth components that assisted in appropriate growth and development may be the cause of the higher grain yield growth of the grain soybean. These results were similar with the findings of Maurya and Rath (2000) who reported that grain yield was maximum with the application of 60 kg P ha⁻¹

4.10.3 Interaction effect of phosphorus and Sulphur fertilizers on the grain yield of soybean

The highest grain yield of soybean (67.92g) was recorded with the treatment combination of S_2P_2 . On the other hand, the lowest grain yield of soybean (46.31g) was recorded in the P_0S_0 treatment (control) combination. Numerical variation has been

observed. It has increased numerically with the increase dose of combined fertilizer. From the results it was found that though the grain yield was insignificant but 46.63% yield was increased in S_2P_2 treatment over control (S_0P_0). 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. Due to fertilizers' beneficial effects on yield qualities, grain production rose when phosphorus and sulfur levels rose to optimal levels.

Table 9 Effect of Sulphur and Phosphorous on the yield Attributing Parameters

Treatment	Stem Diameter (mm)	Pod Length (cm)	Pods plant ⁻¹ (no.)	Seeds plant ⁻¹ (no.)	Seeds pod ⁻¹ (no)	100-seed weight (g)	Grain yield (g/m ²)	Stover Yield (g/m ²)	Biological Yield (g/m ²)	Harvest index (%)
Level of sulphur										
S ₀	3.6544	2.9600b	30.011	89.94	2.9867b	11.11	48.278c	88.333	136.61	35.498b
S ₁	3.8367	3.2778a	33.333	100.90	3.0156b	11.667	55.631b	93.333	148.96	37.336ab
S ₂	3.9411	3.3044a	34.511	113.44	3.2733a	12.222	59.466a	94.889	154.35	38.467a
<i>P</i>	0.60	0.01	0.58	0.30	0.00	0.45	0.01	0.53	0.14	0.05
Level of phosphorus										
P ₀	3.7256	2.8889b	30.178	93.19	3.0700b	10.667	49.920c	85.667	135.59	37.013
P ₁	3.8189	3.3489a	31.889	96.11	3.0022b	11.778	53.590b	95.00	148.59	36.026
P ₂	3.8878	3.3044a	35.789	114.98	3.2033a	12.556	59.864a	95.889	155.75	38.261
<i>P</i>	0.85	0.0001	0.44	0.30	0.02	0.12	0.02	0.19	0.09	0.18
CV (%)	15.96	7.95	21.67	19.32	4.48	15.82	13.20	13.80	12.67	6.60
S ₀ =0 kg S ha ⁻¹ S ₁ =6.51 kg S ha ⁻¹ S ₂ =9.76 kg S ha ⁻¹ P ₀ =0 kg P ha ⁻¹ P ₁ =14 kg P ha ⁻¹ P ₂ = 21 kg P ha ⁻¹										

A column followed by similar letters is not statistically different according to Duncan's Multiple Range Test ($P \leq 0.05$)

4.11.1 Effect of Sulphur on the stover yield of soybean

Among the different doses of S fertilizer, S_2 (20 kg S ha⁻¹) showed the highest stover yield of soybean (94.89). On the contrary, the lowest weight of stover yield of soybean (83.33) 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.

4.11.2 Effect of phosphorus on the stover yield of soybean

The highest stover yield of soybean (95.88) was recorded in P_2 , which was statistically similar with P_1 treatment. The lowest stover yield (85.65) 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.

4.11.3 Interaction effect of sulphur and phosphorous fertilizer on the stover yield of soybean

The highest stover yield of soybean (100) was recorded with the treatment combination of S_2P_2 which was statistically similar with the treatment S_1P_1 . On the other hand, the lowest stover yield of soybean (82) was recorded in the S_0P_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 Sulphur and Phosphorous.

4.12.1 Effect of Sulphur on the biological yield of soybean

Among the different doses of S fertilizer, S_2 (20 kg S ha⁻¹) showed the highest biological yield of soybean (154.35). On the contrary, the lowest in biological yield of soybean (136.61) was recorded in the S_0 treatment where no Sulphur fertilizer was applied. As a result of the combined beneficial effects of the grain and stover yield, it is possible to conclude that sulfur enhanced the biological yield.

Table 10: Interaction effect of Sulphur and Phosphorous on the yield Attributing Parameters

Interaction (S x P)	Stem Diameter (mm)	Pod Length (cm)	Pods plant ⁻¹ (no.)	Seeds plant ⁻¹ (no.)	Seeds pod ⁻¹ (no)	100-seed weight (g)	Grain yield (g/m ²)	Stover yield (g/m ²)	Biological Yield (g/m ²)	Harvest index (%)
S₀P₀	3.67	3.13bc	27.06	78.98	2.90def	10.33	46.31	82	128.31	36.32
S₀P₁	3.87	3.10bc	30.23	90.53	2.98cdef	11.33	47.48	90.33	137.82	34.55
S₀P₂	3.41	2.64d	32.73	100.32	3.07bcd	11.66	51.03	92.67	143.70	35.61
S₁P₀	3.61	2.73cd	30.73	93.72	3.05cde	10.66	50.43	85.67	136.10	37.25
S₁P₁	3.69	3.46ab	32.06	101.77	3.13bc	11.66	55.82	99.33	155.16	35.95
S₁P₂	4.20	3.63a	37.20	107.20	2.85f	12.66	60.63	95	155.63	38.80
S₂P₀	3.89	2.80cd	32.73	106.87	3.25b	11.00	53.01	89.33	142.35	37.46
S₂P₁	3.89	3.48ab	33.36	96.03	2.88ef	12.33	57.45	95.33	152.79	37.57
S₂P₂	4.04	3.63a	37.43	137.43	3.68a	13.33	67.92	100	167.93	40.36
P	0.67	0.00	0.99	0.87	0.00	0.99	0.78	0.98	0.96	0.77
CV (%)	15.96	7.95	21.67	19.32	4.48	15.82	13.20	13.80	12.67	6.60
S ₀ = 0 kg S ha ⁻¹ S ₁ = 6.51 kg S ha ⁻¹ S ₂ = 9.76 kg S ha ⁻¹ P ₀ = 0 kg P ha ⁻¹ P ₁ = 14 kg P ha ⁻¹ P ₂ = 21 kg P ha ⁻¹										

A column followed by similar letters is not statistically different according to Duncan's Multiple Range Test ($P \leq 0.05$)

4.12.2 Effect of phosphorus on the biological yield of soybean

The highest biological yield of soybean (155.7) was recorded in P_2 (63 g). The lowest biological yield (135.5) was recorded in the P_0 treatment where no phosphorus was applied. The increased grain yield in ratio to the stover yield from phosphorus treatment may be the cause of the biological yield rise.

4.12.3 Interaction effect of phosphorus and Sulphur fertilizers on the biological yield of soybean

The highest biological yield of soybean (167.9) was recorded with the treatment combination of S_2P_2 . On the other hand, the lowest biological yield of soybean (128.3) was recorded in the P_0S_0 treatment (control).

4.13.1 Effect of Sulphur on the Harvest Index of soybean

It is shown in the table 9 the highest harvest index was (38.46%) recorded in S_2 . The lowest harvest index (35.49%) was recorded in the S_0 treatment where no Sulphur was applied.

4.13.2 Effect of phosphorus on the Harvest Index of soybean

The highest harvest index was (38.26%) recorded in P_2 . The lowest harvest index (37.01%) was recorded in the P_0 treatment where no Phosphorous was applied.

4.13.3 Interaction effect of phosphorus and Sulphur fertilizers on the harvest index of soybean

The highest harvest index of soybean (40.36%) was recorded with the treatment combination of S_2P_2 . On the other hand, the lowest biological yield of soybean (34.56%) was recorded in the S_0P_1 treatment. The findings support those of Shubhangi et al. (2014), who found that the interaction between phosphorus and sulfur significantly affected the harvest index. The harvest index improved dramatically with increasing phosphorus and sulfur levels, reaching 26.40 kg P and 40 kg S ha^{-1} (Singh et al, 1999).

4.14.1 Effect of Sulphur and Phosphorous doses on proximate composition of soybean

4.14.1.1 Dry Matter in soybean seed

The highest dry matter in the seed (87.43%) was recorded with the S_2P_2 treatment combination. On the other hand, the lowest dry matter (78.8%) in seed was observed in S_0P_0 which was statistically similar with S_0P_1 treatment combination. Application of

sulfur increases the protein concentration in soybean seeds, which is directly correlated with higher dry matter content. Phosphorus administration increases root development and enhances nutrient absorption, which raises the dry matter content of soybean seeds (Grant *et al.*, 2001).

4.14.1.2 Crude Protein content in soybean seed

The highest protein content in the seed (36.025%) was recorded with the S₂P₂ treatment combination. On the other hand, the lowest protein content (22.41%) in seed was observed in S₀P₂ treatment combination. According to Majumdar *et al.* (2001) and Tomar *et al.* (2004), there was an increase in protein content with the higher rate of S and P. Here we have found that the protein content increased with the increasing level of fertilizer treatment.

4.14.1.3 Crude Fiber in Soybean Seed

The highest amount of crude fiber was recorded in the seed was (8.76%) in S₁P₂ treatment combination. On the contrary the lowest amount of crude fiber was found (3.83%) in S₁P₀ treatment combination.

4.14.1.4 Ether Extract in Soybean Seed

The highest amount of ether extract was in the seed was (11.87%) in S₁P₁ which was statistically similar with S₁P₂ treatment combination. On the other hand, the lowest amount (7.54%) was in S₂P₁.

4.14.1.5 Ash in Soybean seed

The highest amount of ash was in the seed was (7.83%) in S₁P₁ which was completely similar with S₁P₂ treatment combination. On the other hand, the lowest amount was found in S₂P₁.



Table: 11 Nutritional Composition of Soybean Seed

Treatment	DM%	CP%	CF%	EE%	Ash%	Carb %	NFE %	GE (MJ)
S ₀ P ₀	78.8	22.92	7.38	8.6	7.13	61.35	53.97	463.03
S ₀ P ₁	78.98	24.18	6.59	8.78	7.34	59.70	53.11	465.13
S ₀ P ₂	79.54	22.41	8.38	8.95	4.16	64.48	56.10	476.24
S ₁ P ₀	81	26.50	3.83	8.56	7.64	57.29	53.46	466.45
S ₁ P ₁	82.7	29.4	4.81	11.87	7.83	50.90	46.09	487.85
S ₁ P ₂	78.9	32.55	6.24	8.66	7.83	50.96	44.72	475.88
S ₂ P ₀	75.98	27.38	7.64	10.76	7.32	54.53	46.89	480.84
S ₂ P ₁	84.65	32.55	8.76	7.54	4.04	55.87	47.11	485.48
S ₂ P ₂	87.43	36.02	7.96	10.32	6.54	47.12	39.16	495.52
DM= Dry Matter, CP=Crude Protein, CF=Crude Fiber, EE=Ether Extract, Carb=Carbohydrate, NFE=Nitrogen Free Extract and GE=Gross Energy								

4.14.1.6 Carbohydrate in Soybean Seed

The highest Carbohydrate in the seed (155.72%) was recorded with the S₂P₂ treatment combination. On the other hand, the lowest carbohydrate (135.086%) in seed was observed in S₁P₀ treatment combination. Through influencing photosynthetic efficiency and development, sulfur feeding has a major impact on the amount of carbohydrates present in seeds. (Scherer, 2001; Zhao *et al.*, 1999). Reduced carbohydrate buildup in seeds caused by phosphorus deficit in soybeans can impact seed production and quality. A study conducted in by Kant *et al* (2011). showed that a sulfur shortage in soybeans caused changes in the way carbohydrates were metabolized, resulting in lower amounts of soluble sugars and less starch building up in the seeds. In soybeans, phosphorus deprivation changed the way carbohydrates were metabolized, which led to lower amounts of sugars and starch in the seeds, according to research by Hammond *et al.* (2009).

4.14.2 Effect of Sulphur and Phosphorous levels on the micro and macro nutrients content of soybean seed

4.14.2.1 Sulphur

The highest amount of Sulphur (553.49ppm) was found in S₂P₂ and the lowest (301.89ppm) was recorded in the S₀P₁ treatment combination. The amount of sulphur increases with the increase of fertilizer level.

Sulfur fertilization dramatically raised the sulfur content in soybean seeds, according to research by Malhi *et al.* (2017). They saw a favorable correlation between increasing seed sulphur content and sulphur treatment, which improved the nutritional value of soybeans. Sulphur treatment raised the sulphur content of soybean seeds, according to research by Zhao *et al.* (2014), demonstrating a clear correlation between sulfur availability and seed sulfur accumulation.

Sufficient amounts of phosphorus in the soil can influence how much sulphur soybeans absorb and use, which in turn affects how much sulphur is in the seeds of soybeans (Zhang *et al.*, 2010). A balanced sulfur and phosphorus treatment may have increased the efficiency of sulfur absorption and sulfur content in soybean seedlings (Li *et al.* 2017).

4.14.2.2 Phosphorous

The highest amount of Phosphorous (1293.01%) was found in S₂P₁ and the lowest (825.27%) was recorded in the S₀P₀ control treatment combination. The amount of P increases with the increase of fertilizer level.

Research by Mengel and Kirkby (1987) found that phosphorus deficit can lower per plants absorption of the mineral, which lowers the amount of phosphorus in soybean seeds. Fertilizing soybean seedlings with phosphorus greatly raised their phosphorus content. (Mallarino *et al.* 2011) assessed how fertilizer phosphorus affected the phosphorus absorption and seed content of soybeans. The findings showed that seed phosphorus content may be increased by applying phosphorus at the proper rates. Phosphorus absorption and utilization are influenced by sulfur. Fismes *et al.* (2000) found that soybeans may absorb less phosphorus if they have a sulfur shortage. The study emphasized the role sulfur plays in helping plants absorb phosphorus. The interaction between phosphorus and sulfur in soil can influence their availability to soybean plants. Research by Kelling *et al.* (2003) investigated the effects

of sulfur application on soybean phosphorus nutrition and yield. The study emphasized the importance of balancing phosphorus and sulfur levels in soil for optimal soybean production.

Table 12. Macro and Micro Nutrients Content of Soybean Seed

Treatment	Sulphur (ppm)	Phosphorous (ppm)	Nitrogen (%)	Potassium (ppm)	Iron (ppm)
S ₀ P ₀	366.35	825.27	3.668	15085.84	33.50
S ₀ P ₁	301.89	1158.60	3.869	18857.30	44.70
S ₀ P ₂	527.03	1190.86	3.586	17128.03	70.16
S ₁ P ₀	530.02	1163.98	4.241	19236.08	63.03
S ₁ P ₁	565.89	1142.47	4.704	20619.49	150.61
S ₁ P ₂	519.47	1265.67	5.208	17852.67	154.71
S ₂ P ₀	534.40	1083.33	4.382	17642.32	79.33
S ₂ P ₁	562.95	1293.01	5.208	22002.91	159.34
S ₂ P ₂	553.49	1045.69	5.764	17852.67	163.47

4.14.2.3 Nitrogen

The highest amount of Nitrogen (5.76%) was found in S₂P₂ and the lowest (3.58%) was recorded in the S₀P₂ treatment combination. The amount of N % increases with the increase of fertilizer level. According to Zhang *et al.* (2018), fertilizing with sulfur greatly improved the efficiency of nitrogen absorption and use in soybean plants, increasing the amount of nitrogen in the seeds. According to a study by Li *et al.* (2018), applying phosphorus to soybean plants enhanced their ability to assimilate nitrogen and maximize its use. As a result, soybean seeds absorb more nitrogen. Furthermore, phosphorus administration was observed to raise the nitrogen content in soybean seeds in a study by Sevgi *et al.* (2017), showing a beneficial relationship between phosphorus and nitrogen absorption. Soybeans with optimal amounts of phosphorus can enhance nitrogen absorption and assimilation, resulting in higher nitrogen content in the seeds.

4.14.2.4 Potassium

The highest amount of Potassium (22002.91ppm) was found in S₂P₁ and the lowest (15085.84ppm) was recorded in the S₀P₁ treatment combination. The amount of Potassium increases with the increase of fertilizer level.

An investigation conducted by Kumar *et al.* (2017) showed that the administration of P and S together markedly increased the amount of nutrients, including K, in soybean seeds. This study found that seeds with the greatest K content were those that had been treated with 45-kilogram S ha⁻¹ and 90 kg P₂O₅ ha⁻¹. It has been demonstrated that adequate sulfur availability enhances potassium absorption. In this regard, Zhao *et al.* (1999) found that sulfur fertilizer increased the potassium content in oilseed rape, a plant whose sulfur and potassium needs are comparable to those of soybeans. In comparison to applying either nutrient alone, a balanced application of sulfur and phosphorus improved total nutrient absorption, including potassium, according to research by Haq and Mallarino (2000) on soybean.

4.14.2.5 Iron

The highest amount of Iron (170.47ppm) was found in S₂P₂ and the lowest (33.50ppm) was recorded in the S₀P₀ control treatment combination. The amount of Fe increases with the increasing level of fertilizer.

It has been demonstrated that adding sulfur to soybean seeds increases their iron content by improving the plant's internal iron absorption and transport systems. Phosphorus deficit may hinder the effectiveness of iron absorption and use in soybean plants, which may ultimately result in a decrease in the amount of iron in soybean seeds.

Table 13. Association of Growth Parameters of Soybean at harvesting

	Plant Height at harvest	Branch number after harvest	Number of pods per plant	Number of seed per pod	Stover yield	Seed Yield	Biological Yield	Harvest Index
Plant Height at harvest	1							
Branch number at harvest	0.75***	1						
Number of pods per plant	0.74***	0.87***	1					
Number of seed per pod	0.79***	0.89***	0.95***	1				
Stover yield	0.83***	0.90***	0.85***	0.82***	1			
Seed yield	0.74***	0.72***	0.79***	0.82***	0.71***	1		
Biological Harvest	0.86***	0.89***	0.89***	0.89***	0.94***	0.89***	1	
Harvest Index	0.038	0.29	0.077	0.14	-0.21	0.52**	0.10	1

***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$

There was highly positive significance association between plant height and branch number at harvest ($r=0.75$), plant height and number of pod per plant ($r=0.74$), number of pod per plant and branch number ($r=0.87$), number of seed per plant and plant height ($r=0.79$), number of seed per pod with branch number ($r=0.89$), number of seed per pod with number of pod per plant ($r=0.95$), stover weight and plant height ($r=0.83$), stover weight and number of pod per plant ($r=0.79$), stover yield and branch number ($r=0.90$), stover yield and number of seed per pod ($r=0.82$), seed weight and plant height ($r=0.74$), seed yield and branch number ($r=0.72$), seed yield and number of seed per pod ($r=0.79$), seed yield and number of seed per pod ($r=0.82$), Seed Yield and stover yield ($r=0.71$), Biological harvest and plant height ($r=0.86$), biological yield and branch number ($r=0.89$), biological yield and number of pod per plant ($r=0.89$), biological yield and number of seed per pod ($r=0.94$), biological yield and seed yield ($r=0.89$).

Table 14 Association of Growth Parameters and Nutritional composition of Soybean

	DM%	Ash%	CP%	CF%	EE%	Plant Height at Harvest (cm)	Number of Pod per plant	Seed Yield
DM%	1							
Ash%	-0.48	1						
CP%	0.60	0.02	1					
CF%	0.16	-0.72	0.09	1				
EE%	-0.17	0.44	0.16	-0.24	1			
Plant Height at Harvest (cm)	0.36	-0.19	0.47	0.21	0.66*	1		
Number of Pod per plant	0.12	-0.05	0.70**	0.27	0.14	0.52	1	
Seed Yield (gm/m ²)	0.50	-0.08	0.87***	0.24	0.27	0.70**	0.83*	1

***= $p<0.001$, **= $p<0.01$, *= $p<0.05$

There was highly positive significance association between seed yield and CP ($r=0.70$). There is also significant association between number of pods per plant and CP ($r=0.70$), seed yield and plant height at harvest ($r=0.70$).

CHAPTER V



SUMMARY AND CONCLUSION

With a view to investigating the effect of phosphorus and Sulphur fertilizers on the growth, yield and nutritional quality of soybean an experiment was conducted at the Professor Dr. Purnendu Gain Field Laboratory of Agrotechnology Discipline, Khulna University. The experiment was laid out following two factors randomized complete block design with 9 treatments combinations having unit plot size of 6m^2 and replicated three times. Three doses of sulphur viz $S_0 = 0\text{ kg S ha}^{-1}$, $S_1 = 6.51\text{ kg S ha}^{-1}$ $S_2 = 9.76\text{ kg S ha}^{-1}$ and three doses of phosphorous $P_0 = 0\text{ kg P ha}^{-1}$ $P_1 = 14\text{ kg P ha}^{-1}$ $P_2 = 21\text{ kg P ha}^{-1}$ were used in this experiment as the treatments.

Soybean seeds were sown on the 11 November 2023 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 22 February 2024. Intercultural operations were done whenever required in order to support normal plant growth. Five plants were randomly collected plot wise to record the data on for plant height (cm), number of leaves per plant, number of per branches plant, chlorophyll content, stem diameter, pod length, number of pods per plant, number of seeds per plant, hundred seed weight (g), grain yield (gm/m^2) and stover yield (gm/m^2) and biological yield(gm/m^2) and harvest index (%)

Plant height was significantly affected by different levels of P and S. Plant height increased with increasing levels of S and P up to highest level. The individual application of sulphur, S_2 gave the tallest plant (40.36 cm), whereas application of Phosphorous, P_2 produced the tallest plant of (40.8cm) height. The tallest plant (40.93 cm) was found in S_2P_2 treatment combination, which was higher over control treatment combination (35.56cm).

The individual application of S and P showed positive effect on the number of leaves per plant, number of branches per plant, chlorophyll content, stem diameter, pod length, number of pods per plant, number of seeds per pod, number of seeds per plant, hundred seed weight (gm), grain yield (gm/m^2) and stover yield (gm/m^2). All the plant characters increased with increasing levels of S and P up to certain level and sometimes up to the

maximum level.

Seed yield was increased with increasing levels of S and P up to certain level. The highest seed yield (59.46g/m^2) was found in plants receiving sulphur in S_2 and the lowest was recorded in S_0 (48.27) treatment. The individual application of Phosphorous produced the highest amount of seed yield (59.86g/m^2) in P_2 . The combined application of S and P had positive effect on seed yield of soybean. The highest seed yield of soybean (67.92g/m^2) was recorded in S_2P_2 treatment. The lowest yield (46.31g/m^2) was recorded in S_0P_0 treatment. Combined application of S and P produced higher grain yield compared to control treatment.

With the increasing level of S and P fertilizer the amount of DM, CP, CF and EE increases. The highest amount of DM was (87.43 ppm) in S_2P_2 combination. The highest amount of CP was (36.02 ppm) in S_2P_2 combination. Again, the highest amount of CF, EE and carbohydrate were (7.96ppm), (10.32ppm) and (155.72ppm) respectively recorded in S_2P_2 combination.

The amount of micro and macro nutrients in soybean seed (N and Fe) were also highest in S_2P_2 treatment combination. They were (N= 5.76%) (Fe= 170.47ppm) respectively. The amount of micro and macro nutrients in soybean seed (S, P and K) were recorded high in S_1P_1 (S= 565.89ppm) S_1P_2 (P= 1265.67ppm) S_2P_1 (K= 22002.91ppm) treatment combination respectively.

With an increase in fertilizer, there was a rise in plant height, number of branches per plant, number of leaves per plant, stem diameter, pod length, number of pods per plant, number of seeds per plant, hundred seed weight, grain yield, stover yield, and biological yield. There was a rise in the interaction effects of phosphorus and sulfur on yield characteristics. The combined application of 9.77 kg S ha^{-1} and 21 kg P ha^{-1} was shown to boost the majority of growth and yield attributing factors.

As the sulphur and phosphorous doses increased the DM, CP, CF, EE were also increased. Nutrient content of seed like N, P, K, S and Fe showed higher values with higher doses of S and P.

CHAPTER VI

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Measuring Stem Diameter



Grinding the seed



Weighing Seed



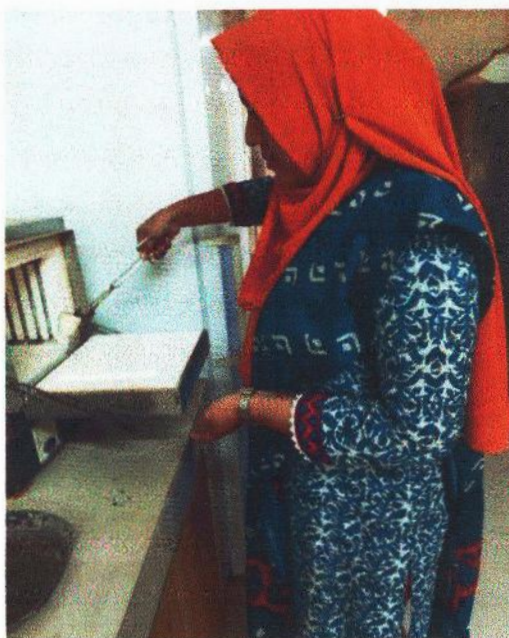
Weighing the sample



Weighing the sample for analysis



Ash determination



Giving Ash in muffle furnace



CP determination