EFFECT OF NITROGEN AND SULPHUR ON YIELD AND SEED QUALITY OF GROUNDNUT

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CERTIFICATE

This is to certify that the thesis entitled, "EFFECT OF NITROGEN AND SULPHUR ON YIELD AND SEED QUALITY OF GROUNDNUT" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in SEED TECHNOLOGY, embodies the result of a piece of bona-fide research work carried out by ***Most. Gulshanara Khatun,*** *Registration no.15-06741 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

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-Author

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ABSTRACT

A field experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during the period from February to August 2021 in Kharif season, to study the effect of nitrogen and sulphur on yield and seed quality of groundnut. The experiment consisted of two factors, and followed split plot design with three replications. Factor A: Different levels of nitrogen 4) *viz;* N_0: 0 kg Urea ha^{-1}/0 kg Nitrogen ha^{-1}, N_1: 20 kg Urea ha^{-1} /9.2 kg Nitrogen ha^{-1}, N_2: 25 kg Urea ha^{-1}/11.5 kg Nitrogen ha^{-1} and N_3: 30 kg Urea ha^{-1}/13.8 kg Nitrogen ha^{-1} and Factor B: Different levels of sulphur (4) *viz;* S_0: 0 kg Gypsum ha^{-1} /0 kg Sulphur ha^{-1}, S_1: 250 kg Gypsum ha^{-1}/45 kg Sulphur ha^{-1}, S_2: 300 kg Gypsum ha^{-1} /54 kg Sulphur ha^{-1} and S_3: 350 kg Gypsum ha^{-1}/63 kg Sulphur ha^{-1}. The analysis of various data revealed that significant differences were observed in groundnut growth, yield, and quality characteristics as a result of nitrogen and sulphur application doses and their treatment combination. In case of different levels of nitrogen application the highest pod yield (2.06 t ha^{-1}), kernel yield (1.65 t ha^{-1}), seed protein content (27.14 %), seed oil content (49.59 %), seed nitrogen content (4.34 %), seed sulphur content (0.27 %) and seed germination percentage (90.58 %) were reported in N_3 treatment followed by N_2 treatment. Seed yield and quality of parameters of groundnut increased with increased sulphur fertilizer application and the highest pod yield (1.95 t ha^{-1}), kernel yield (1.56 t ha^{-1}), seed protein content (24.79 %), seed oil content (46.16 %), seed nitrogen content (3.97 %), seed sulphur content (0.24 %) and seed germination percentage (91.42 %) were recorded in S_3 treatment. In respect of the combination effect, the highest pod yield (2.37 t ha^{-1}), kernel yield (1.95 t ha^{-1}), seed protein content (29.56 %), seed oil content (51.62 %), seed nitrogen content (4.73 %), seed sulphur content (0.29 %) and seed germination percentage (96.33 %) were achieved in N_3S_3 treatment combination. However N_2S_3 treatment combination showed statistically similar results in pod yield and N_3S_1 and N_3S_2 treatment combination showed statistically similar results in nutrients content in groundnut seed. Therefore it may be concluded that both nitrogen and sulphur had beneficial effect on yield and quality seed production of groundnut. Application of nitrogen (25-30 kg Urea ha^{-1}) and sulphur (300-350 kg Gypsum ha^{-1}) along with their combination exhibited the best performance on yield and quality seed production compared to other treatment combination.

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ABBREVIATIONS

Full word	Abbreviations
Agriculture	Agr.
Agro-Ecological Zone	AEZ
Bangladesh Bureau of Statistics	BBS
Biology	Biol.
Botany	Bot.
Cultivar	Cv.
Dry weight	DW
Editors	Eds.
Emulsifiable concentrate	EC
Environments	Environ.
Food and Agriculture Organization	FAO
Fresh weight	FW
International	Intl.
Journal	J.
Least Significant Difference	LSD
Liter	L
Triple super phosphate	TSP
Science	Sci.
Soil Resource Development Institute	SRDI
Technology	Technol.
Serial	Sl.

CHAPTER-I

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) or peanut is the sixth most important oilseed crop in the world cultivated throughout the tropical and subtropical areas, followed by cereal crops. In Bangladesh, groundnut is the second most oilseed crop and has played a pivotal role in meeting the growing oil requirements in recent years to ensure nutritional security for a population of over 160 million (Shakil, 2022). Nutritionally, groundnut seeds contain 48-50% edible oil, 22–29% protein, and 20% carbohydrate, with an average yield of 2.30-3.00 t ha^{-1} (Dun *et al.*, 2019). The portions of kernel are additionally plentiful of E, K vitamins and all B nutrients with the exception of B_{12}. It is the richest plant source of thiamine and niacin, which is lowest in cereals. Groundnut haulm is utilized as animal feed. Groundnut cultivated in 2019 was about 32,000 ha of land and the total production was about 47,000 mt in Bangladesh (Azad *et al.*, 2020). Groundnut is a major crop in the char lands of Bangladesh, but because of poor yields, farmers derive a limited income from the crop.

Crop performance, yield and quality are the results of genotypic expression, which are modulated by continuous interaction with the environment and other factors. The applications of suitable nutrients are the most important factor which affects the growth and development of the plant. It is necessary to apply the optimum doses of fertilizers to obtain better growth and development of plant for higher yield. Excessive use of chemical fertilizers to meet the crop demand has badly affected the soil health and productivity and is also adding high economic load but at the present condition it is not possible to completely eliminate the use of chemical fertilizers. The applications of suitable nutrients are very important factor which affects the growth and development of plant. Application of nutrients like nitrogen, potassium, sulphur, magnesium, molybdenum, zinc, copper and boron are advantageous as they furnish availability of nutrients and enhances uptake of applied nutrients (Mouri *et al*., 2018).

Among the major nutrients, nitrogen is the most vital one. Nitrogen is fundamental for enthusiastic vegetative and regenerative development of plant, photosynthesis and production of assimilates for pod filling. It is a fundamental part of many components of plant, like chlorophyll, proteins, nucleotides, chemicals, alkaloids, enzymes and nutrients (Sagvekar *et al.,* 2017). It is the key element that stimulates root and shoot growth. Although groundnut plant fixes a portion of nitrogen to meet the crop requirement, additional nitrogen supplement to groundnut crop are very crucial. The impact of nitrogen fertilizer addition on soil natural matter status and soil substantial properties is critical to agrarian manageability and to build up crop yield. Besides, N fertilization influences dry matter generation as well as N collection and apportioning into different portions of yield plants for the development, advancement and other activities (Devi *et al*., 2022).

Besides NPK, application of inorganic S is very essential for having better growth and biosynthesis of protein and chlorophyll in plants (Narayana *et al.*, 2020). This important nutrient is available to plants only as sulfate (Chowdhury *et al.,* 2020), hence most S fertilizers consist of sulfate salts. In the last few decades, S requirements for plants have gained special attention due to its increased deficiency in soil and reduction in crop yield and quality (Zenda *et al*., 2021). The deficiency of S resulted in retarded growth, reduced leaf size, and caused leaf chlorosis (Chowdhury *et al.,* 2020). For optimum plant growth, the requirement of S varies between 0.1 and 0.5% of the dry biomass weight (Marschner, 2012). The morphology of chloroplast is generally affected by S deficiency due to the presence of functional chloroplasts which are normally rich in S (Veazie *et al.,* 2020). In addition, photosynthesis has been retarded in a profound way because of S deficiency which can be corrected slowly through the addition of external S (Abadie and Tcherkez, 2019). Sulphur is likewise progressively perceived as the fourth important plant supplement close to NPK (Devi *et al*., 2022). Oil seed crops expect about the similar amount of S or more than, phosphorous for high return and quality of crop (Jamal *et al.*, 2010). The application of sulphur enhanced the uptake of several macro and mirco nutrients by groundnut (Chowdhury *et al.,* 2020). Sulphur is also help to promote nodulation in legumes which help in promoting nitrogen fixation and increasing the production of high nutritional and market quality crops (Ariraman and Kalaichelvi, 2020). Inspite of being a crucial nutrient liable for synthesis of several amino acid and fatty acids in oilseed crops, sulphur is seldom given recognition. Hence, there is requirement for a systematic study on effect of sulphur fertilization of groundnut. The positive impact of sulphur nutrient application to groundnut was accounted for by Ramdevputra *et al.* (2010).

Soil analysis of Bangladesh soils has indicated that the soils are medium to low in the nitrogen and deficient in sulphur. Nitrogen and sulphur play vital roles in plant nutrition. Individual and combined effect of these nutrients on yield and yield attributes are not well documented, though these factors play an important role in groundnut production. Keeping these considerations in view an experiment was planned with the following objectives,

i. To monitor the effect of nitrogen and/or sulphur levels on growth, yield and quality of groundnut seed, and
ii. To find out the optimum level of nitrogen and sulphur for maximizing yield and quality of groundnut seed.

CHAPTER II

REVIEW OF LITERATURE

In this section, an attempt was made to collect and study relevant information available regarding the effect of nitrogen and sulphur on yield and seed quality of groundnut in order to gather knowledge useful in carrying out the current piece of work. Because the available literature on this crop is limited, the literatures on other related crops were also gathered and reviewed under the following headings:

2.1 Effect of nitrogen

2.1.1 Effect on growth parameters

Vijayakumar and Geethalakshmi (2018) found that in groundnut applying 67.93 kg N ha^{-1} resulted in significantly higher plant height (31.21 cm), dry matter production (7781.32 kg ha^{-1}), leaf area index (4.52 cm), number of matured pods $plant^{-1}$ (24.84), 100-seed weight (68.69 g), pod yield (2087.03 kg ha^{-1}), and haulm yield (5355.59 kg ha^{-1} (54.25 and 40.76 kg ha^{-1}) of nitrogen.

Meena *et al.* (2011) reported that, when compared to control and 20 kg N ha^{-1}, the application of 40 kg N ha^{-1} significantly improved growth parameters of groundnut such as dry matter accumulation and number of nodules $plant^{-1}$, as well as yield parameters such as number of pods $plant^{-1}$, test weight, number of kernels pod^{-1}, pod yield, haulm yield, and biological yield.

In comparison to no nitrogen application, Pareek and Poonia (2011) found that nitrogen application at 60 kg ha^{-1} increased overall vegetative growth, branching, number of pods $plant^{-1}$ (79%), shelling percentage (15%), seed index (27.2%), pod index (12.2%), pod yield, and benefit cost ratio of groundnut.

Field trail conducted by Reddy *et al.* (2011) reported that plant height, leaf area index and dry matter production of groundnut increased with application of 60-80-100 kg N, P_2O_5 and K_2O ha^{-1} during *rabi* under irrigated conditions on sandy loam soils of Tirupati, Andhra Pradesh.

Chudhari *et al*. (2009) concluded that the application of 100% RDF 25-50-0 NPK kg ha^{-1} significantly increased the plant height (42.0 cm), number of branches $plant^{-1}$ (6.0) and dry matter accumulation (37.0 g $plant^{-1}$) of summer groundnut as compared to 25% and 50% RDF, but it was at par with 75% RDF on loamy sand soils of Gujarat.

Kausale *et al.* (2009) stated that 100% recommended dose of nutrients @ 25 kg N and 50 kg P_2O_5 ha^{-1} registered significantly higher dry matter production in groundnut on clay soils at Navsari, Surat.

Krishna *et al*. (2009) reported that in groundnut application of recommended dose of fertilizer at 25-50-25 NPK kg ha^{-1} + vermicompost at 2.5 t ha^{-1} + gypsum at 500 kg ha^{-1} significantly increased the plant height (32.11 cm) and number of branches $plant^{-1}$ (7.85) during *kharif* on medium black soils of Hiriyur, Karnataka.

Venkateswarlu (2005) reported that the application of 100% RDF (12.5 kg N and 25 kg P_2O_5 ha^{-1}) recorded the highest plant height (30.8 cm) of groundnut compared to control during *kharif* on clayey soils of College of Agriculture, Junagadh, Gujarat.

Uma *et al.* (2004) revealed that application of 100% recommended dose of fertilizer recorded the highest plant height, leaf area index and dry matter accumulation in groundnut over control.

Gogoi *et al* . (2000) investigated the effect of different nitrogen fertilizer rates using five doses (0, 20, 40, 60, and 80 kg N ha^{-1}) and discovered that increasing the nitrogen level up to 80 kg N ha^{-1} increased the number of pods $plant^{-1}$, shelling percentage, number of branches $plant^{-1}$, and number of pegs $plant^{-1}$ of groundnut, while 40 kg N ha^{-1} was determined to be the optimum dose because yield an increase.

Subrahmaniyan *et al.* (2000) observed that in groundnut increase in the dose of NPK fertilizer up to 150% significantly recorded the maximum plant height.

Patra *et al*. (1995) observed that application of NPK at different levels resulted in increased plant height, leaf area index and DMP of groundnut.

Barik *et al.* (1994) found increased groundnut plant height, number of branches, dry matter accumulation, LAI, CGR, NAR and PGR with increased dose of NPK fertilizer.

Edna *et al*. (2000) reported that leaf area duration, leaf area index and leaf net assimilation rate increased with increase in nitrogen dose in all genotypes of groundnut studied and concluded that 25 kg N ha^{-1} was necessary for optimal yield.

2.1.2 Effect on yield and quality parameters

Devi *et al*. (2022) conducted an experiment during Zaid season (Summer season) of 2021, at crop research farm of Department of Agronomy, SHUATS, Prayagraj (U.P.) with the goal to evaluate the impact of different levels of nitrogen and sulphur on growth and yield of summer groundnut (*Arachis hypogaea* L.) under Randomized block design comprising 9 treatments, with 3 levels of nitrogen along with 3 different levels of sulphur that are replicated thrice. The results revealed that treatment T9 (50 kg ha^{-1} N + 40 kg ha^{-1}S) has recorded maximum plant height (56.95 cm), number of nodules $plant^{-1}$ (48.20), plant dry weight (42.98 g $plant^{-1}$), crop growth rate (7.11 g m^2 $plant^{-1}$), relative growth rate (0.005 g $g^{-1}day^{-1}$), number of pods $plant^{-1}$ (20.60), kernels pod^{-1} (2.00), seed index (41.17g), pod yield (2741.00 kg ha^{-1}) and haulm yield (4371.00 kg ha^{-1}) at the time of harvest and harvest index (36.74%) was highest with T_6 (40 kg ha^{-1} N + 40 kg ha^{-1} S).

Hasan *et al*. (2021) carried out a study to find the effect of nitrogen (N) and phosphorus (P) fertilizers on the growth, yield, nodulation, the proximate and nutritional composition of bambara groundnut [*Vigna subterranea* (L.) Verdc.]. Experimental results showed that N and P fertilizers were found to play a dominating role in increasing the vegetative growth and yield. Plant height (20.65), pod number (45.75) and harvest index (41.61) increased significantly with the application of N 30 + P 60 kg ha^{-1}. Application of N 30 P 60 kg ha^{-1} significantly influenced nodulation and nitrogen yield. Protein, fibre, Mg and amino acid contents increased with N 30 P 60 kg ha^{-1}. The application of N 30 P 60 mg kg^{-1} had increased the growth, yield, nodulation, proximate and nutritional composition of groundnut.

Mondal *et al.* (2020) carried out an investigations during the winter seasons 2015–2016 and 2016–2017 at the district seed farm of Bidhan Chandra Krishi Viswavidyalaya, West

Bengal, India (23°26’ N, 88°22′ E, elevation 12 m above mean sea level) to facilitate the comprehensive study of plant growth, productivity and profitability of an irrigated peanut crop under varied levels of nitrogen: with and without a rhizobium inoculants and with and without polythene mulch. Quality traits and nutrient dynamics were also itemized. Fertilizing with 100% of the recommended dose of nitrogen combined with rhizobium inoculant and polythene mulch significantly enhanced peanut plant growth, yield and yield-attributing traits, resulting in the maximum fertilizer (i.e., nitrogen, phosphorus and potassium) uptake by plant parts.

Bijarnia *et al.* (2019) conducted a field experiment was at Agronomy farm, S. K. N. College of Agriculture, Jobner (Rajasthan) during the Kharif 2016, to study the effect of nitrogen and potassium on growth, yield and nutrient uptake of sesame (*Sesamum indicum* L.) under loamy sand soil of Rajasthan. The experiment comprised of four levels of Nitrogen (0, 20, 40, 60 kg N ha^{-1}) and four levels of Potassium (0, 10, 20, 30 kg K_2O ha^{-1}), thereby making 16 treatment combinations was laid out in a randomized block design and replicated three times. Results indicated that progressive increase in level of nitrogen up to 40 kg ha^{-1} significantly increased the plant height and dry matter accumulation $plant^{-1}$ at all the growth stages, number of branches $plant^{-1}$, number of leaves $plant^{-1}$, leaf area index, and chlorophyll content over the preceding levels. Yield and total N, P and K uptake also increased significantly with nitrogen at 40 kg ha^{-1} and further increase in nitrogen level to 60 kg ha^{-1} could not enhance the above parameters significantly.

Noorhosseini and Damalas (2018) conducted a field experiment in Astaneh-ye Ashrafieh of Guilan Province in northern Iran to evaluate the environmental impact of peanut (*Arachis hypogaea* L.) production under three levels of nitrogen used (N) (0, 30, and 60 kg $ha^{−1}$) in the form of urea fertilizer. Six categories of environmental impact (i.e., global warming potential, acidification potential, terrestrial eutrophication potential, depletion of fossil resources, potassium resources, and phosphate resources) were determined. The functional unit was assumed the production of one ton of peanut pod yield. Peanut pod yield increased by 48.8% with N rate 30 kg $ha^{−1}$ and by 108.6% with N rate 60 kg $ha^{−1}$, compared with control (without N fertilization).

According to Chirwa *et al.* (2017), the application of 20 kg N ha^{-1} resulted in an increase in pod yield, kernel yield, and N uptake by groundnut plants when compared to the control.

Vaghasia and Bhalu (2016) reported the highest values of growth and yield attributing characters of groundnut viz., plant height (33.0cm), number of branches plant^{-1} (5.82), number of pods plant^{-1} (24.01), shelling (71.91%),100 kernel weight (55.75g), highest pod (3007 kg ha^{-1}) and haulm (4682 kg ha^{-1}) yield kernel yield (1993 kg ha^{-1}), SMK (87.88%) and seed count (51.44) were recorded when nutrient applied N @ 50 kg ha^{-1}, K @ 50 kg ha^{-1} and S @ 40 kg ha^{-1}.

Kumar *et al.* (2014) conducted a field experiment at Main Agricultural Research Station (MARS), Dharwad to examined the effect of nitrogen and phosphorus levels and ratios on yield and nutrient uptake by groundnut in northern transition zone of Karnataka. Groundnut cultivar JL 24 was tried during 2012 with eleven ratios of nitrogen (N) and phosphorus (P_2O_5) fertilizers with potassium level as constant (25 kg K_2O ha^{-1}). The yield attributing characteristics, dry pod yield and nutrient uptake were increased due to increasing N/P fertilizer ratios from 0.00 to 1.00. The treatment receiving N/P fertilizer ratio of 0.50 (30 kg N, 60 kg P_2O_5 , 25 kg K_2O ha^{-1}) produced significantly higher dry pod yield (3310 kg ha^{-1}), number of filled pods plant^{-1} (17.47), total number of pods plant^{-1} (18.80) and 100 kernel weight (38.50 g). Further, the same treatment recorded significantly higher uptake (147.04 kg N, 23.30 kg P_2O_5, 118.48 kg K_2O, 10.93 kg S ha^{-1}) as compared to all other N/P fertilizer ratios. The treatment receiving N/P fertilizer ratio of 0.50 (30 kg N, 60 kg P_2O_5, 25 kg K_2O ha^{-1}) produced higher kernel yield (2441 kg ha^{-1}). However, it was on par with the treatment receiving N/P fertilizer ratio of 0.33 (2344 kg ha^{-1}).

Iman and Ahmed (2014) concluded that the application of 60 kg N ha^{-1} resulted in highest plant height, number of pods plant^{-1}, shelling percentage, number of seeds pod^{-1}, seed oil content and protein content of groundnut.

Sharma *et al.* (2014) reported higher N, P and K uptake by peanut plants under 100% of the recommended N dose applied with *Rhizobium* inoculation.

El-Habbasha *et al* (2013) reported that the increase in N levels from 30 to 40 kg N ha^{-1} significantly increased number of pods $plant^{-1}$, weight of pods $plant^{-1}$, weight of seeds $plant^{-1}$, 100-seed weight, pod yield $plant^{-1}$, seed yield $plant^{-1}$and straw yield $plant^{-1}$ in groundnut crop.

The results of an experiment conducted by Reddy *et al.* (2011) reported that the application of 60-80-100 kg N, P_2O_5 and K_2O ha^{-1} resulted in significant increase in pod and haulm yields of groundnut during *rabi* under irrigated conditions.

In comparison to the control, Ali and Seyyed (2010) found that in peanut applying 60 kg N ha^{-1} resulted in considerably greater pod production (2314 kg ha^{-1}) and kernel yield (1378 kg ha^{-1}).

According to Gohari and Niyaki (2010), application of 60 kg N ha^{-1} resulted in a higher shelling percentage of peanut than one control and 30 kg N ha^{-1}.

Thomas and Thenua (2010) stated that in groundnut basal application of 75% recommended dose of fertilizer (RDF) 20-80-20 NPK produced higher number of pods $plant^{-1}$ (24.0), shelling percentage (67.88) and 100 kernel weight (56.3 g) compared to 25% and 50% RDF but it was at par with 100% RDF during *kharif* on sandy loam soils of Allahabad Agricultural Institute.

Chudhari *et al*. (2009) concluded that the application of 100% RDF 25-50-0 NPK kg ha^{-1} significantly increased the number of pods $plant^{-1}$ (22.0), 100 kernel weight (43.2 g) and shelling percentage (70.9) of summer groundnut as compared to 25% and 50% RDF, but it was at par with 75% RDF on loamy sand soils of Gujarat.

Krishna *et al*. (2009) reported that in groundnut application of recommended dose of fertilizer at 25-50-25 NPK kg ha^{-1} + vermicompost at 2.5 t ha^{-1} + gypsum at 500 kg ha^{-1} recorded significantly higher number of pods $plant^{-1}$ (16.17) pod yield (3211 kg ha^{-1}) during the *kharif* on medium black soils of Hiriyur, Karnataka.

Shinde *et al.* (2000) showed that application of 100% RDF (25: 50: 0 kg NPK ha^{-1}) produced maximum pod yield (43.41 q ha^{-1}) and haulm yield (88.18 q ha^{-1}), maximum hundred pod weight, hundred kernel weight, protein yield, protein content, oil content and oil yield of groundnut than the other treatments.

Dasani *et al*. (1999) reported that there was significant increase in oil percent, oil yield, protein content and protein yield of groundnut kernel due to application of the half and full recommended (25 kg N + 50 kg P ha^{-1}) doses of fertilizer as compared to the control.

2.2 Effect of sulphur

2.2.1 Effect on growth parameters

An experiment was conducted by Sarkar *et al.* (2019) at Mymensingh to study the effect of sulphur on yield of groundnut. They took five levels of sulphur (0, 15, 30, 45, and 60 kg ha^{-1}) and reported that growth parameters like leaf area index (2.03), dry matter plant^{-1} (50.36 g), number of primary branches plant^{-1} (10.33 cm), and number of secondary branches plant^{-1} (9.27 cm) were found significantly the highest with 60 kg S ha^{-1}.

Shaikh *et al.* (2019) conducted an experiment during the *kharif* 2017 at Parbhani to study the effect of land configurations and sulphur levels on growth and yield of sesamum (*Sesamum indicum* L.) revealed that the application of RDF (50:25 NP kg ha^{-1}) with 30 kg sulphur ha^{-1} recorded higher mean plant height (cm), number of functional leaves plant^{-1}, leaf area plant^{-1}, number of branches plant^{-1} and total dry matter plant^{-1}.

Patel *et al*. (2018) conducted an experiment at Anand during summer season of 2017 to evaluate the effect of sulphur and potassium on yield attributes, yield and quality of summer groundnut. The results of experiment revealed that application of sulphur @ 40 kg ha^{-1} recorded significantly higher dry matter content (4.43 g) at 45 DAS and number of branches plant^{-1} (7.81) and it was remains at par with 20 kg S ha^{-1}.

Yadav *et al.* (2018) conducted a field experiment at Jobner during *kharif*, 2015 in order to evaluate the performance of groundnut under varying levels of sulphur and its sources. The results of experiment revealed that CGR of the crop during 0-35 DAS was significantly increased upto application of sulphur at the rate of 45 kg ha^{-1}. Application of sulphur at 60 kg ha^{-1} recorded significantly higher RGR over 15 kg ha^{-1} during 70 DAS to at harvest stage. Likewise, 60 kg S ha^{-1} also significantly increased the plant height, number of total and effective nodules as well as dry weight of nodules $plant^{-1}$.

A field experiment was carried out by Singh *et al.* (2017) during the *rabi* season of 2015-16 at B.H.U., Varanasi, to evaluate the effect of land configuration and sulphur levels on yield attribute, yield and economics of Indian mustard. They observed that 40 kg S ha^{-1} recorded the highest plant height, more leaf area index, a greater number of branches $plant^{-1}$ and significantly higher dry matter accumulation $plant^{-1}$ than lower level at 30,60, 90 DAS and at harvest.

Ramakrishna *et al.* (2017) conducted at Dharwad an experiment to evaluate the effect of sources and levels of sulphur on growth of sesame during the *kharif* season of 2012. They revealed that application of sulphur @ 40 kg ha^{-1} recorded significantly higher plant height (125.36 cm), number of primary branches (3.0), leaf area $plant^{-1}$ (4.63 cm^2), leaf area index (1.55) and leaf area duration (80.75). The treatment apply 30 kg S ha^{-1} recorded on par the results with 40 kg S ha^{-1}.

Debbarma (2016) conducted an experiment at Parbhani during the summer season of 2015 to evaluate the response of groundnut to sulphur fertilization under different land configuration in the summer season. They observed that 60 kg S ha^{-1} recorded significantly higher growth attributes like plant height, number of branches leaf area $plant^{-1}$, pegs $plant^{-1}$ and nodules $plant^{-1}$ over 20 kg and 0 kg S ha^{-1}.

A field experiments was conducted by Rao *et al.* (2013) at Seethampeta, Andhra Pradesh to study the effect of sources and levels of sulphur on sandy clay loam soil with test variety K6. The results of the experiment revealed that application of sulphur @ 45 kg ha^{-1} through gypsum recorded the highest plant height of groundnut.

A field study was conducted by Vaghasia *et al.* (2007) at Junagadh during the *kharif* seasons of 2002 and 2003 to evaluate effect of sulphur application on physicochemical properties of soils and yield of groundnut. The results of experiment revealed that sulphur application @ 50 and 25 kg ha^{-1} produced equally effective and increased dry matter and root volume in 2003 as well as plant height and pod yield during both the years.

2.2.2 Effect on yield and quality parameters

A field experiment was carried out by Ariraman and Kalaichelvi (2020) at Madurai to study the effect of sulphur on groundnut. The results revealed that sulphur @ 60 kg ha^{-1} recorded higher number of pods $plant^{-1}$, pod yield and oil quality in groundnut.

Sarkar *et al.* (2019) conducted an experiment at Mymensingh to evaluate the impact of sulphur on yield and yield parameters of groundnut. They took five levels of sulphur (0, 15, 30, 45, and 60 kg ha^{-1}). They reported that application of sulphur @ 60 kg ha^{-1} produced the highest number of pegs $plant^{-1}$ (46.27), number of pods $plant^{-1}$ (37.81), pod yield (31.3 q ha^{-1}), seed yield (26.7 q ha^{-1}), haulm yield (68.4 q ha^{-1}), 100-pods weight (96.83 g), 100- kernels weight (46.24 g), shelling percentage (85.30%) and harvest index (31.37%).

Shaikh *et al.* (2019) conducted an experiment during the *kharif* 2017 at Parbhani in order to study the effect of land configurations and sulphur levels on growth and yield of sesamum (*Sesamum indicum* L.). The results revealed that the sulphur level RDF (50:25 NP kg ha^{-1}) + 30 kg sulphur recorded significantly higher yield attributes, seed yield (629 kg ha^{-1}), straw yield (1652 kg ha^{-1}) and harvest index (27.54%) over the rest of all treatments and found at par with RDF (50:25 NP kg ha^{-1}) + 20 kg sulphur.

Pandey *et al*. (2018) conducted an experiment at Faizabad, U.P. to assess the impact of different sulphur and phosphorus levels on yield and quality parameters of groundnut. The results revealed that the application of 40 kg S ha^{-1} significantly increased the yield by 38.7 percent over the control. Protein content and oil content in groundnut kernels increased significantly with P and S and the maximum value of protein (27.09%) content and oil content (49.72%) were observed with application of sulphur @ 40 kg ha^{-1}.

Parmar *et al.* (2018) conducted experiment during the summer season of 2015-16 at the Hill millet research station N.A.U., waghai, India, with twelve treatment combinations consisting of three sources of sulphur *viz.* A_1: Elemental sulphur, A_2: Gypsum and A_3: Ammonium sulphate and four levels of sulphur *viz*. S_0: 0 kg ha^{-1}, S_1: 10 kg ha^{-1}, S_2: 20 kg ha^{-1}, S_3: 30 kg ha^{-1} and the result revealed that the significantly highest quality attributes were recorded with application of ammonium sulphate (A_3) source and 30 kg ha^{-1} (S_3) levels of sulphur.

An experiment was conducted by Patel and Zinzala (2018) during summer of 2016 at KVK Farm, Waghai, Gujarat to evaluate the effect of sulphur and boron fertilization on nutrient content and uptake pattern nutrient in groundnut. The findings of experiment showed that increasing levels of sulphur led to a significant increase in the content and uptake of N, P, K, S and B by pods and haulm up to 45 Kg S ha^{-1}.

Patel *et al.* (2018) conducted an experiment during summer season of the year 2017 at Anand to study the effect of sulphur on yield attributes, yield and quality parameters of summer groundnut. The results indicated that application of sulphur @ 40 kg S ha^{-1} gave significantly the highest number of pod plant^{-1} (12.19), shelling% (73.80%), seed index (41.02 g), pod yield (2083 kg ha^{-1}) and haulm yield (4349 kg ha^{-1}). They also observed that quality parameters of groundnut were improved with increased levels of sulphur. Significantly higher protein content (27.48%), oil content (43.75%) as well as N (4.40%), P (0.36%), K (0.80%) and S (0.38%) content in pod and higher N (91.68 kg ha^{-1}), P (18.87 kg ha^{-1}), K (16.75 kg ha^{-1}) and S (7.98 kg ha^{-1}) uptake by pods were recorded under treatment involving 40 kg S ha^{-1}. However, it was found at par with 20 kg S ha^{-1}.

Yadav *et al.* (2018) conducted a field experiment during *kharif* of 2015 at Jobner to study the response of groundnut to various levels and sources of sulphur. The results of experiment showed that significantly higher pod (1832 kg ha^{-1}) and biological yields of groundnut (5361 kg ha^{-1}) recorded with application of 60 kg S ha^{-1} followed by 45, 30 and 15 kg S ha^{-1}.

A field experiment was conducted by Pancholi *et al.* (2017) at SKNAU, Jobner in loamy sand soil of Rajasthan during *kharif* season 2013 to study the effect of sulphur application on yield and quality of groundnut. They found that application of sulphur at 60 kg ha^{-1}gave the highest pod yield, kernel yield, haulm yield, seed index, total sulphur uptake (15.37 kg ha^{-1}) and oil yield (684.5 kg ha^{-1}) as compared to preceding levels.

Banu *et al.* (2017) conducted a field experiment at Anand during summer season of the year 2015 to study the effect of sulphur and bio-fertilizer on growth, yield and quality of summer groundnut. The findings of experiment revealed that level of sulphur significantly influenced all the yield attributing characters, pod and haulm yield. Application of sulphur at 40 kg ha^{-1}through gypsum recorded a significant increase in pod and haulm yield.

Debbarma (2016) conducted an experiment during the summer season of 2015 at Parbhani to evaluate the response of groundnut to sulphur fertilization under different land configuration in summer season. He found that the developed pods and number of pods plant^{-1}, pod yield, haulm yield and harvest index were found higher with 40 kg S ha^{-1} followed by 60 kg S ha^{-1}. Whereas, shelling percentage, 100 kernel weight, protein content and oil content in kernel were not affected significantly due to different levels of sulphur.

A pot experiment was conducted by Sisodiya *et al.* (2016) to examine the effects of different sources of sulphur (cosawet, gypsum, bentonite and elemental sulphur) on nutrient uptake and yield of *kharif* groundnut variety GG 7. Before sowing, pot soil was fertilized with different sources of sulphur at five diferent levels *viz*. 0, 5, 10, 15, and 20 mg sulphur/kg of soil. The results indicated that application of elemental sulphur @ 20 mg kg^{-1} recorded the highest uptake and leaf content of phosphorous (0.113% and 43.29 mg plant^{-1}) and potassium (0.558% and 213.79 mg plant^{-1}) in plant at harvesting.

A field experiment conducted at Odisha by Dash *et al*. (2013) to study the effect of sulphur on growth and pod yield of groundnut. The results of experiment reported that the highest pod yield (1800 kg ha^{-1}) and sulphur use-efficiency were recorded with application S @ 20 kg ha^{-1}and the highest (47.90%) oil content was recorded with 60 kg S ha^{-1}.

A field experiments was conducted by Rao *et al.* (2013) at Seethampeta, A.P. during *rabi* seasons of 2010-11 and 2011-12 to evaluate the effect of sources and sulphur levels on groundnut (*cv*. K 6). The results revealed that 45 kg S ha^{-1} through gypsum recorded the highest number of filled pods plant^{-1}, 100-pod weight, 100- kernel weight, pod yield, haulm yield and oil content of the kernels.

Giri *et al*. (2011) carried out an experiment at Bidhan Chandra Krishi Viswavidyalaya during pre-*kharif* season to evaluate the effect of different levels of sulphur on yield and water use efficiency of groundnut. The results expound that yield attributing characters and kernel yield significantly affected by sulphur levels. Application of sulphur @ 15 kg ha^{-1}gave maximum crop water-use efficiency.

Ramdevputra *et al*. (2010) conducted field experiment at Agricultural Research Station, Dhari (Gujarat) during *kharif*, 2008 to study the effect of sulphur application on yield of groundnut and soil fertility under rainfed agriculture and maximum pod yield (1914 kg ha^{-1}) were recorded with application of sulphur through SOP in addition to recommend dose of fertilizer (12.5: 25 kg N, P_2O_5 ha^{-1}) increase the oil and protein content in kernel.

A field experiment was carried out by Yadav *et al.* (2010) at Allahabad during *rabi* season of 2003-04 to the study the effect of sulphur levels (0, 20, 40 and 60 kg ha^{-1}) and source of biofertilizer @ 200 g 10 kg^{-1} of seed inoculated on yield of mustard and soil properties. They reported that the maximum yield was obtained by the sulphur application at 40 kg ha^{-1}.

A field experiment was conducted by Ahlawat and Rajat (2009) during two consecutive *kharif* seasons of 2003 and 2004 at IARI, New Delhi to evaluate the effect of FYM and sulphur fertilization on pigeonpea + groundnut intercropping system. They revealed that the sulphur application @ 35 and 70 kg ha^{-1}, being at par, recorded significant increase in yield and nutrient uptake in groundnut over 0 kg S ha^{-1}. The sulphur use efficiency indices were higher at lower level (35 kg S ha^{-1}).

Patel *et al.* (2008) conducted a field experiment at Sardarkrushinagar to find out optimum level of sulphur and effective source of sulphur for summer groundnut. The results of experiments revealed that the pod yield was increased with successive increase in level of sulphurr up to 40 kg ha^{-1} (3.70 t ha^{-1}). Maximum WUE (4.92 kg ha^{-1}) recorded at both the levels, *i.e.*, 40 and 60 kg S ha^{-1}.

Tathe *et al.* (2008) conducted experiment during summer season of 2006 on the effects of sulphur and zinc on groundnut in vertisols and the result revealed that the application of 40 kg S ha^{-1} recorded significantly higher oil and protein content.

A field experiment was conducted by Singh and Mann (2007) at Banasthali, Rajasthan to study the effect of sulphur and zinc on groundnut. They revealed that significantly higher pod yield of groundnut obtained with 40 kg S ha^{-1} which is remain at par with 60 kg S ha^{-1}. The sulphur use effeciency decreased with increasing levels of sulphur and maximum sulphur use efficiency was recorded at 20 kg S ha^{-1}.

A field study was conducted by Vaghasia *et al.* (2007) to study the effect of land configuration, subsoiling and sulphur application on physico-chemical properties of soils and yield of groundnut during the *kharif* seasons of 2002 and 2003 at Junagadh. The results of experiment transpired that sulphur fertilization @ 50 and 25 kg ha^{-1}recorded significantly higher pod yield during 2003, 2004 and pooled over control. On an average, application of sulphur @ 50 kg $ha^{-1}$and 25 kg ha^{-1}increased pod yield by 9.8 and 8.8% and haulm yield by 7.3 and 5.6% over control respectively.

Jamal *et al.* (2006) conducted an experiment at Jamia Hamdard, New Delhi to study the interactive effect of sulphur and nitrogen on seed and oil yield of groundnut. The results revealed that 20 kg sulphur + 43.5 kg nitrogen ha^{-1} recorded significant the highest seed yield (3130 kg ha^{-1}), biological yield (9333 kg ha^{-1}), harvest index (35.53%), number of pods $plant^{-1}$ (36.33), seed index (39.10 g), oil content (50.5%), protein content (30.31%), nitrogen content (4.83%) in kernel and sulphur content (0.25%) in kernel.

Singh *et al.* (2005) carried out a field experiment at Banasthali, Rajasthan to study the effect of sulphur on pod yield of groundnut. The results of experiment showed that application of S @ 60 kg ha^{-1} recorded 29.2% higher pod yield over the control. The sulphur uptake by pods significantly increased with increasing levels of sulphur and 60 kg S ha^{-1} recorded maximum sulphur uptake (10.89 kg ha^{-1}) by pods.

Samui and Adhikary (2004) reported that the application of sulphur contributed to the enhanced proportion of oleic acid (18:1) and decrease that of linoleic acid (18:2) without significantly influencing the level of other fatty acids in the mature kernels, linoleic fatty acid (18:2) increased with corresponding decrease in the content of oleic acid (18:1) by the application of sulphur.

Majumdar and Kumar (2002) carried out experiment during the rainy seasons of 1998 and 1999 on relative performance of sulphur sources on sulphur nutrition of groundnut *(Arachis hypogaea* L.*)* in acid Alfisol of Meghalaya and the result showed that application of S @ 30 kg ha^{-1} proved superior to other levels in respect of oil, protein content and S uptake by groundnut.

CHAPTER III

MATERIALS AND METHODS

The materials and methods used in the experiment were organized in this chapter, which includes a brief overview of the experimental location, groundnut variety, soil, climate, land preparation, experimental design, treatments, soil and plant sample collection cultural operations, and analytical methods. Here were the specifics of the research method.

3.1 Experimentation site description

3.1.1 Location

The research was carried out during the rabi season at the Sher-e-Bangla Agricultural University Farm, Sher-e-Bangla Nagar, Dhaka-1207, from February to August 2021. It is located at latitude 90.2^0N and longitude 23.5^0E. The precise location of the experimental site is depicted on a map (Appendix -I)

3.1.2 Soil

According to Bangladesh soil classification, the soil in the experimental field was from the Tejgaon series of AEZ No. 28, Madhupur Tract and was classified as Shallow Red Brown Terrace Soils. A composite sample was prepared prior to the experiment by collecting dirt from various locations across the field at depths ranging from 0 to 15 cm. Before testing for physical and chemical properties, the soil was air-dried, crushed, and sieved through a 2 mm sieve. Appendix II describes some of the soil's early physical and chemical characteristics.

3.2 Climatic condition

The experimental site's climate is subtropical, with three distinct seasons: the monsoon season from November to February, the pre-monsoon period or hot season from March to April, and the monsoon season from May to October. Appendix IV shows the monthly average temperature, humidity, and rainfall during the crop growing season as collected from Weather Yard, Bangladesh Meteorological Department.

3.3 Planting materials

BARI Chinabadam-10 was used as the plant material for conducting the experiment. BARI Chinabadam-10 is a high yielding variety of groundnut was developed by the Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh. The variety was released in 2016 by the authorization of National Seed Board. It takes about 140-155 days to mature in *rabi* season and 120-135 days during *kharif* season. Pod and kernels are medium bold sized. The cultivar gives a pod yield of maximum 2.5 t ha^{-1}, average 2 t ha^{-1}. This is one of the best varieties so far released by BARI.

3.4 Experimental treatment

There were two factors in the experiment, namely, different levels of nitrogen and sulphur as mentioned below:

Factor A: Different levels of nitrogen (4) *viz;*

N_0: 0 kg Urea (control) ha^{-1}	0 kg Nitrogen ha^{-1}
N_1: 20 kg Urea ha^{-1}	9.2 kg Nitrogen ha^{-1}
N_2: 25 kg Urea ha^{-1}	11.5 kg Nitrogen ha^{-1}
N_3: 30 kg Urea ha^{-1}	13.8 kg Nitrogen ha^{-1}

Factor B: Different levels of sulphur (4) *viz;*

S_0: 0 kg Gypsum ha^{-1}	0 kg Sulphur ha^{-1}
S_1: 250 kg Gypsum ha^{-1}	45 kg Sulphur ha^{-1}
S_2: 300 kg Gypsum ha^{-1}	54 kg Sulphur ha^{-1}
S_3: 350 kg Gypsum ha^{-1}	63 kg Sulphur ha^{-1}

3.5 Seed collection

Seeds of BARI Chinabadam-10 were collected from Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh.

3.6 Design and layout of experiment

The experiment was laid out in a split-plot design with 2 factors and three replications. Total 48 unit pots were made for the experiment. According to the experimental design, each block was then assigned to 16 treatment combinations. The size of unit plot was 3.8 m × 1.8 m. Row to row and plant to plant distances were 30 cm and 15 cm, respectively. The distance between the two plots was 0.5 m, and the blocks were 1 m apart. Appendix III shows the layout of the experimental plot.

3.7 Field preparation

The experiment plot was opened with a power tiller on the 1st February, 2021 and left exposed to the sun for a week. After one week, the land was harrowed, ploughed, and cross-ploughed several times before laddering to achieve good tilth. Weeds and stubbles were removed, and a desirable tilth of soil was obtained for seedling transplantation. Drainage channels were built around the land to avoid water logging caused by rainfall during the study period. When the plot was finally ploughed, the soil was treated with Furadan 5G at a rate of 15 kg ha^{-1} to protect the young seedlings from cut worm attack.

3.8 Manure and fertilizer application

Application of organic manure through cowdung was done well before 7 days of seed sowing (during field preparation time). The groundnut crop was fertilized with 5 ton cowdung, 160 kg TSP, 85 kg MoP, and 10 kg Boric acid. The application of N through urea, and S through Gypsum was done as per the treatments requirement. Fertilization (basal dose) was completed on 11 February, 2021. Half of urea along with other fertilizers as per treatment were applied during final land preparation as basal dose and thoroughly mixed with soil. The rest half urea was applied at 45 days after sowing (DAS) when flowers were initiated by side dressing as per treatment. Gypsum was applied following treatment variables.

3.9 Seed sowing

Before seed sowing, plot soil was irrigated with enough water to achieve the field capacity of soil for seed sowing. The groundnuts were first unshelled and treated with Bavistin 250 WP @ 2 g kg^{-1} seed, then sown in lines maintaining a line to line distance of 30 cm and seed to seed distance of 15 cm having 3 seeds $hole^{-1}$ in the well prepared plot. The seeds were sown on February 13, 2021.

3.10 Intercultural operations

i) Gap filling and thinning

Gap filling and thinning was done at 7 DAS to maintain the uniform plant density in each pot.

ii) Weeding, mulching and irrigation

Regular observation and hand weeding kept the pots weed-free. Mulching and irrigation applications were done when needed.

3.11 General observations of the experimental field

Regular observations were made to see the growth and visual differences of the crops. Incidence of white fly, ants were observed during vegetative growth stage and there were also some mites were present in the experimental pot. The flowering was not uniform.

3.12 Plant protection

The groundnut was sprayed with chloropyriphos to control insect-pests particularly white flies (*Bemisia tabaci)*, the vector for yellow mosaic virus. Single spray was carried out as and when early symptoms of white flies were noticed.

3.13 Harvesting

A general rule of thumb is that the crop should be harvested when approximately 75% of the pods have matured. Following the observation of some maturity indices such as leaf yellowing, leaf spots, pod hardening and toughening, and dark tannin discoloration inside the shell, then the crops were harvested from each pot. The Samples were collected the area of 1 m^2 of each plot avoiding the border plants. During harvest the pod contained 35% moisture. Then the harvested crops were tied into bundles according to treatments and carried to the threshing floor. The pods were then separated from the plants. The sun dried the separated pod and stover by spreading them on the threshing floor. The seeds were separated from the pod and dried in the sun for 3 to 5 days in order to achieve safe seed moisture (8%). Harvesting was completed on August 19, 2021.

3.14 Collection of data

The yield and yield contributing parameters were measured at harvest. Growth, and physiological parameters were recorded on specific date. Data were collected on the following parameters:

a. Growth parameters

i. Plant height (cm)
ii. Number of branches plant^{-1}
iii. Number of leaves plant^{-1}
iv. Dry matter weight plant^{-1} (g)
v. Number of nodules plant^{-1}
vi. Dry weight of nodules plant^{-1} (g)
vii. Number of flowers plant^{-1}

b. Yield and yield contributing parameters:

i. Number of pegs plant^{-1}
ii. Number of pods plant^{-1}
iii. Number of kernel pods^{-1}
iv. 100-seed weight (g)
v. Pod yield (t ha^{-1})
vi. Kernel yield (t ha^{-1})
vii. Haulm yield (t ha^{-1})
viii. Biological yield (t ha^{-1})
ix. Harvest index (%)
x. Shelling (%)

c. Quality parameters

i. Protein content (%)
ii. Oil content (%)
iii. Seed nitrogen content %
iv. Seed sulphur content %
v. Seed germination (%)

3.15 Procedure of recording data

i. Plant height (cm)

The height of the five randomly selected plant from each plot was measured from the ground level to the tip of the plant at 30, 60, 90 DAS and at harvest respectively. Mean plant height of groundnut plant were calculated and expressed in cm.

ii. Number of branches plant^{-1}

The number of branches plants^{-1} from the five randomly selected plant from each plot was counted at 30, 60, 90 DAS and at harvest respectively. The average was calculated and expressed as number of branches plant^{-1}.

iii. Number of leaves plant^{-1}

The number of leaves plants^{-1} from the five randomly selected plant from each plot was counted at 30, 60, 90 DAS and at harvest respectively. The average was calculated and expressed as number of leaves plant^{-1}.

iv. Dry matter weight plant^{-1}

Five representative plants from each net plot were uprooted randomly. Carefully kept in brown paper bags and labeled the samples. These samples were dried in sunlight and then it was kept in oven at 65 ±2°c until constant weight was observed.

v. Number of nodules plant^{-1}

Number of nodules plant^{-1} was measured from randomly selected five plants from each plot at harvest. Nodule number was counted from five plants and mean value was recorded.

vi. Dry weight of nodules plant^{-1}

Nodules were separated from five randomly collected plants and put into envelop and placed in oven maintaining 70°C for 72 hours for oven dry until attained a constant level and the mean nodules dry weight plant^{-1} was determined in gram at harvest.

vii. Number of flowers plant^{-1}

Number of flowers plant^{-1} was counted from the five randomly selected plant from each replication when 85 % flowers appeared in each plot. The average was calculated and expressed as number of flowers plant^{-1} of groundnut.

viii. Number of pegs plant^{-1}

The total number of pegs of five randomly sampled plants from each plot was counted at harvest and average was expressed as number of pegs plant^{-1}.

ix. Number of pods plant^{-1}

The total number of pods of five randomly sampled plants from each plot was counted at harvest and average was expressed as number of pods plant^{-1}.

x. Number of kernel pods^{-1}

The total number of kernels of 10 randomly sampled pods from each plot was taken and the average was expressed as number of kernels pod^{-1}.

xi. 100-seed weight (g)

From the seed stock of each plot 100 seeds were counted randomly and the weight was measured by an electrical balance. It was recorded in gram (g).

xii. Pod yield (t ha^{-1})

The weight of sun dried pods obtained from each net plot after stripping and cleaning were recorded and expressed as t ha^{-1}.

xiii. Kernel yield (t ha^{-1})

Kernel yield was calculated from shelled, cleaned and well dried pod collected from each plot and expressed as t ha^{-1} on 8 % moisture basis.

xiv. Haulm yield (t ha^{-1})

Haulms from the net plot were sun-dried to constant weight and yield was recorded. The haulm yield ha^{-1} was calculated and expressed in t ha^{-1}.

xv. Biological yield (t ha^{-1})

It was the total yield including both the pod and haulm yield as follows:

Biological yield = Pod yield + Haulm yield

xvi. Harvest index (%)

It was computed by dividing the seed yield by the biological yield of groundnut in each treatment and the ratio was expressed as percentage as follows

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

xvii. Shelling (%)

A random sample of 0.2 kg of pods were taken from net plot produce, shelled and the kernel weight was recorded to work out the shelling percentage and expressed in terms of percentage (%) (Singh and Oswalt, 1995)

$$\text{Shelling (\%)} = \frac{\text{Weight of kernel (t)}}{\text{Weight of pods (t)}} \times 100$$

xviii. Protein content (%)

Crude protein content in the kernel was calculated by N estimation of representative oven dried sample. Nitrogen estimation was done by micro Kjeldhal‟s method (Jackson, 1979). Crude protein per cent was computed by multiplying the percentage of nitrogen with the factor 6.25 (Bhuiya and Choudhary, 1974).

xix. Oil content (%)

The oil content in kernel was estimated with the help of Soxhlet's apparatus using petroleum ether as extractant.

xx. Seed nitrogen content %

The N concentration was estimated by micro-kjeldahl method (Piper, 1966) and expressed as %.

xxi. Seed sulphur content %

Sulphur content was determined from the digest of the plant samples (seeds and stover) with $CaCl_2$ (0.15%) solution as described by (Page *et al*., 1982). The digested S was determined by developing turbidity by adding acid seed solution (20 ppm as K_2SO_4 in 6N HCL) and $BaCl_2$ crystals. The intensity of the turbidity was measured by spectrophotometer at 420 nm wave lengths.

xxii. Seed germination (%)

The germination percentage of seed was calculated with the following formula Germination %= (Number of germinated seeds/Total number of set for germination) × 100

3.16 Data analysis technique

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program name Statistix 10 Data analysis software and the mean differences were adjusted by Least Significant Difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

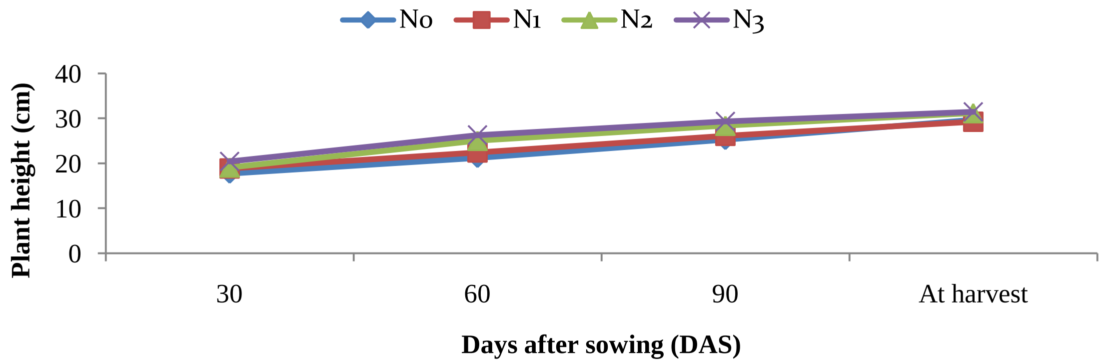
RESULTS AND DISCUSSION

Results obtained from the present study have been presented and discussed in this chapter with a view to studing the effect of nitrogen and sulphur on yield and seed quality of groundnut. The data are given in different tables and figures. The results have been discussed, and possible interpretations are given under the following headings.

4.1 Plant growth characters

4.1.1 Effect of nitrogen and/ or sulphur on plant height (cm)

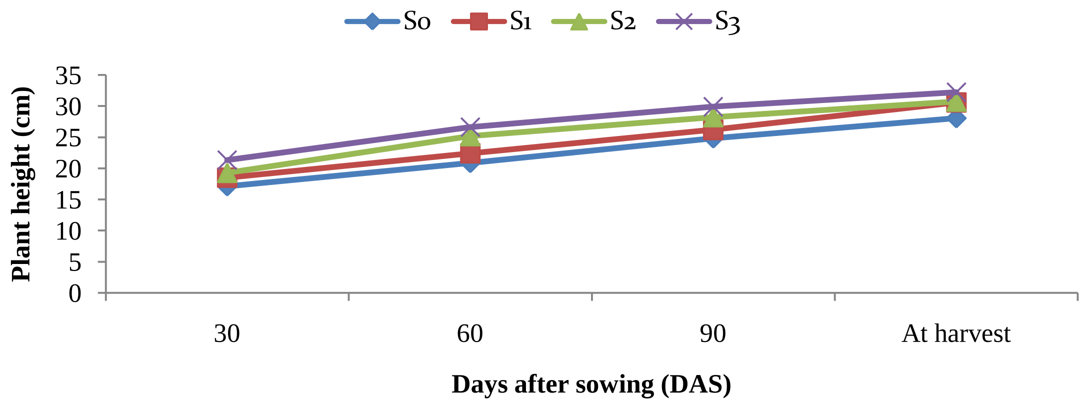
Plant height is an essential character of the vegetative stage of the crop plant and indirectly impacts on yield of crop plants. Application of different doses of nitrogen fertilizers significantly influenced plant height of groundnut at different days after sowing (DAS). It was seen that plant height increased gradually with the age of the crop. Experimental result revealed that the highest plant height (20.48, 26.33, 29.38 and 31.48 cm at 30, 60, 90 DAS, and at harvest respectively) was observed in N_3 (13.8 kg Nitrogen ha^{-1}) treatment which was statistically similar with N_2 (31.22 cm) treatment at harvest respectively. Whereas, the lowest plant height (17.77, 21.26, 25.25 and 29.68 cm 30, 60, 90 DAS, and at harvest respectively) was observed in N_0 (0 kg Nitrogen ha^{-1}) treatment which was statistically similar with N_1 (22.46, 26.13 and 29.25) treatment at 60, 90 DAS, and at harvest respectively (Fig. 1). Nitrogen is an essential nutrient for plant growth. It is a component of chlorophyll, which is necessary for photosynthesis. Nitrogen also helps to form proteins, which are essential for cell growth and development. Nitrogen deficiency can cause stunted growth, yellowing leaves, and reduced yields. Nitrogen fertilization can help to improve plant growth and yield. One of the effects of nitrogen on plant height is that it can increase the number of internodes. Internodes are the sections of a stem that separate the leaves. When there are more internodes, the plant will be taller. The result was similar with the findings of Vijayakumar and Geethalakshmi (2018) who reported that increased application of nitrogen significantly influenced growth parameters of groundnut.



Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

Fig. 1. Effect of doses of nitrogen on plant height at different days after sowing of groundnut ($LSD_{(0.05)}$: 0.94, 1.23, 0.96 and 1.02 at 30, 60, 90 DAS and at harvest, respectively).

The plant height of groundnut varied significantly at various growth stages due to the application of different doses of sulphur fertilizer (Fig. 2). Experimental result showed that the highest plant height (21.33, 26.63, 29.89 and 32.22 cm at 30, 60, 90 DAS, and at harvest respectively) was observed in S_3 treatment, while the lowest plant height (17.12, 20.86, 24.82 and 28.06 cm at 30, 60, 90 DAS, and at harvest respectively) was observed in S_0 treatment. The variation of plant height might be due to the fact that application of sulphur has been reported to improve not only the availability of this nutrient but of other nutrients too, which increase photosynthetic rates and assimilation rates, result in proper for growth and development of groundnut. The result was similar with the findings of Shaikh *et al.* (2019) who reported that the height plant height in groundnut was obtained due to application of recommended dosage of fertilizer plus higher dose of sulphur fertilizer application.



Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Fig. 2. Effect of doses of sulphur on plant height at different days after sowing of groundnut ($LSD_{(0.05)}$: 0.70, 1.26, 1.03 and 0.96 at 30, 60, 90 DAS and at harvest, respectively).

Combined effect of nitrogen and sulphur significantly affected plant height of groundnut at 30, 60, 90 DAS and at harvest respectively (Table 1). According to the experimental findings, the highest plant height (25.19, 29.54, 33.04 and 35.33 cm at 30, 60, 90 DAS, and at harvest respectively) was observed in N_3S_3 treatment combination, which was statistically similar with N_3S_2 (27.95 cm) and N_2S_3 (27.71 cm) treatment combination at 60 DAS; with N_2S_3 (31.12 cm) treatment combination at 90 DAS and with N_2S_3 (34.04 cm) and N_0S_1 (34.15 cm) treatment combination at harvest. While at 30, 60, 90 DAS, and at harvest respectively the lowest plant height (13.47, 18.75, 20.78 and 23.75 cm) was observed in N_0S_0 treatment combination, which was statistically similar with N_0S_1 (20.08 cm), N_1S_0 (19.75 cm) and N_1S_1 (20.24 cm) treatment combinations 60 DAS.

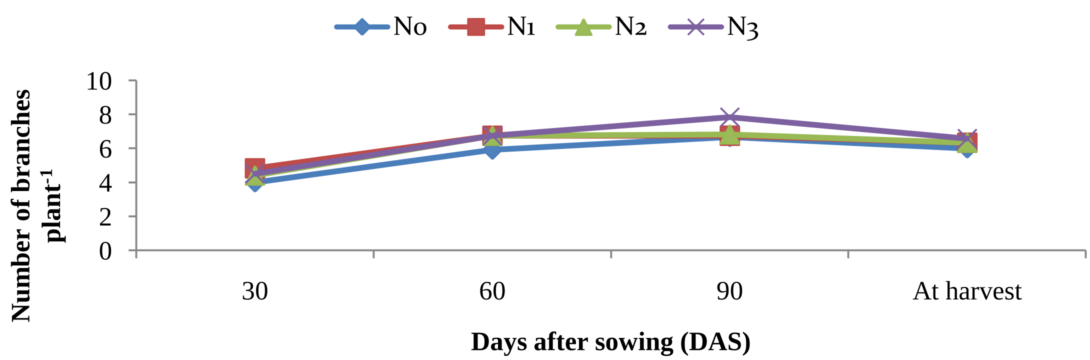
Table 1. Combined effect of nitrogen and sulphur on plant height at different days after sowing of groundnut

Treatment combination	Plant height (cm) at			
	30 DAS	60 DAS	90 DAS	Harvest
N_0S_0	13.47 f	18.75 g	20.78 h	23.75 g
N_0S_1	18.55 c-e	20.08 fg	23.54 g	34.15 ab
N_0S_2	19.26 b-d	22.07 ef	28.59 c-e	31.73 cd
N_0S_3	19.80 bc	24.15 c-e	28.11 c-f	29.08 ef
N_1S_0	17.81 de	19.75 fg	23.27 g	29.42 ef
N_1S_1	19.51 bc	20.24 fg	26.94 ef	28.90 ef
N_1S_2	18.54 c-e	24.75 cd	27.02 d-f	28.24 f
N_1S_3	19.81 bc	25.13 cd	27.27 c-f	30.42 c-e
N_2S_0	17.35 e	21.74 ef	26.19 f	28.74 ef
N_2S_1	18.35 c-e	24.74 cd	27.19 c-f	29.74 ef
N_2S_2	20.22 b	26.03 bc	29.14 bc	32.36 bc
N_2S_3	20.51 b	27.71 ab	31.12 ab	34.04 ab
N_3S_0	19.86 bc	23.21 de	29.04 cd	30.33 de
N_3S_1	17.63 e	24.63 cd	27.18 c-f	29.63 ef
N_3S_2	19.23 b-d	27.95 ab	28.26 c-e	30.63 c-e
N_3S_3	25.19 a	29.54 a	33.04 a	35.33 a
$LSD_{(0.05)}$	1.54	2.51	2.02	1.95
CV(%)	4.41	6.34	4.49	3.77

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

4.1.2 Effect of nitrogen and/ or sulphur on number of branches plant^{-1}

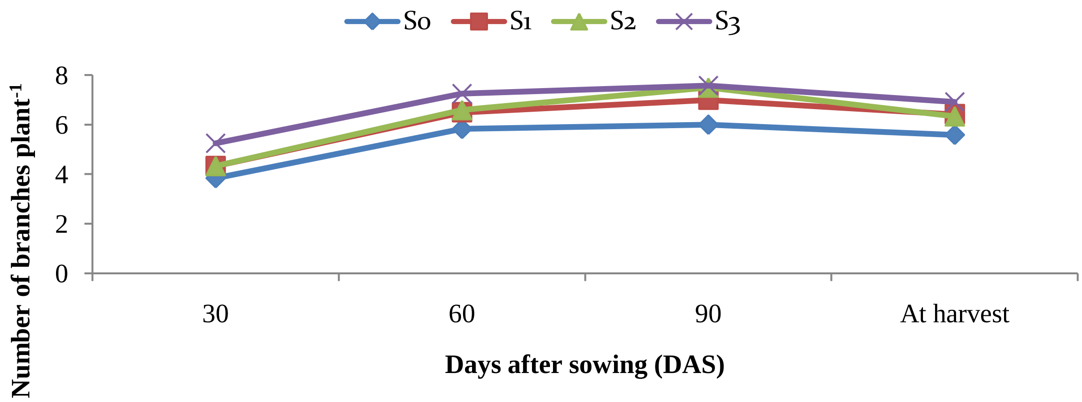
Different doses of nitrogen fertilizers application significantly affected number of branches plant^{-1} of groundnut at 30, 60, 90 DAS, and at harvest respectively (Fig. 3). According to the experimental results, the N_1 treatment had the highest number of branches plant^{-1} (4.83 and 6.75) at 30 and 60 DAS, which was statistically similar with N_2 (6.75) and N_3 (6.75) treatment. At 90 DAS and at harvest, the highest number of branches plant^{-1} (7.84 and 6.58) was observed in N_3 treatment, which was statistically similar with N_1 (6.34) and N_2 (6.34) treatment at harvest. While the lowest number of branches plant^{-1} (4.00, 5.92, 6.67 and 6.00) at 30, 60, 90 DAS, and at harvest was found in N_0 treatment which was statistically similar with N_1 (6.75) and N_2 (6.84) treatment at 90 DAS. The variation of number of branches plant^{-1} might be attributed to the optimum and constant supply and availability of nutrients from organic and inorganic sources, which aid in improved nutrient absorption, eventually promoting cell division and therefore increasing all growth features. Chudhari *et al*. (2009) showed that in groundnut number of branches plant^{-1} was enhanced by increasing nitrogen fertilizers application.



Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

Fig. 3. Effect of doses of nitrogen on number of branches plant^{-1} at different days after sowing of groundnut ($LSD_{(0.05)}$: 0.08, 0.28, 0.32 and 0.27at 30, 60, 90 DAS and at harvest, respectively).

Due to the use of varying sulphur fertilizer doses, groundnut plants produced significantly different numbers of branches at different days after sowing (Fig. 4). According to the experimental results, the highest number of branches plant^{-1} (5.25, 7.25, 7.58 and 6.92) at 30, 60, 90 DAS, and at harvest respectively was observed in S_3 treatment, which was statistically similar with S_2 treatment at 90 DAS. While at 30, 60, 90 DAS, and at harvest respectively, the lowest number of branches plant^{-1} (3.84, 5.83, 6.00 and 5.59) was observed in S_0 treatment. The lowest number of branches plant^{-1} recorded under control treatment might be due to the limited availability of nutrient in soil and uptake of nutrient by the crop, which ultimately reflected on these results. This finds support from the study of Sarkar *et al.* (2019) who reported that increased application of sulphur increased the number of branches plant^{-1} of groundnut.



Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Fig. 4. Effect of doses of sulphur on number of branches plant^{-1} at different days after sowing of groundnut (LSD$_{(0.05)}$: 0.07, 0.29, 0.29 and 0.20 at 30, 60, 90 DAS and at harvest, respectively).

The combined effect of nitrogen and sulphur doses revealed a significant difference in the number of branches plant^{-1} of groundnut at different days after sowing (Table 2). The treatment combination of N_3S_3 recorded the highest number of branches plant^{-1} of groundnut (6.00, 7.67, 8.67 and 7.33) at 30, 60, 90 DAS, and at harvest time, which was statistically similar to N_1S_1 (7.33) and N_2S_3 (7.67) at 60 DAS; with N_1S_3 (7.00) and N_2S_3 (7.33) at harvest respectively. While the lowest number of branches plant^{-1} of groundnut (3.67, 4.67, 5.33 and 5.00) at 30, 60, 90 DAS, and at harvest respectively was observed in N_0S_0 treatment combination, which was statistically similar with N_1S_0 (5.67) treatment combination at 90 DAS.

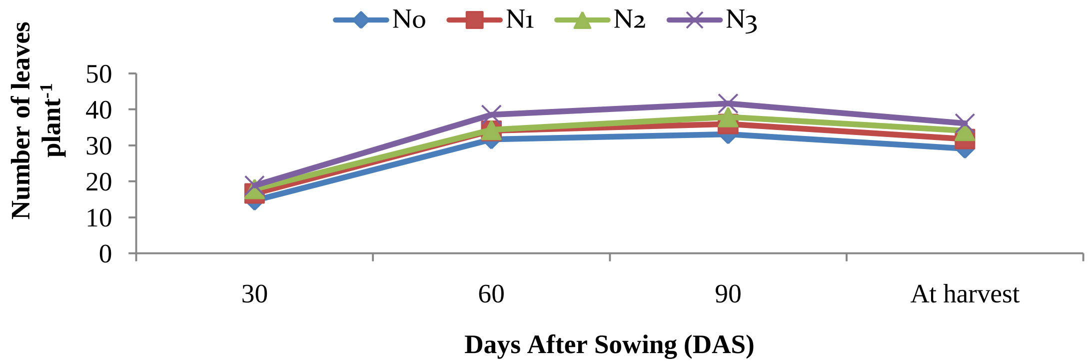
Table 2. Combined effect of nitrogen and sulphur on number of branches plant^{-1} at different days after sowing of groundnut

Treatment combination	Number of branches plant^{-1} at			
	30 DAS	**60 DAS**	**90 DAS**	**Harvest**
N_0S_0	3.67 h	4.67 f	5.33 e	5.00 f
N_0S_1	4.00 g	6.00 e	6.67 d	6.67 bc
N_0S_2	4.00 g	6.33 de	7.67 b	5.67 e
N_0S_3	4.33 f	6.67 cd	7.00 cd	6.67 bc
N_1S_0	4.00 g	6.00 e	5.67 e	5.67 e
N_1S_1	5.33 c	7.33 ab	6.67 d	6.00 de
N_1S_2	4.33 f	6.67 cd	7.33 bc	7.00 ab
N_1S_3	5.66 b	7.00 bc	7.33 bc	6.67 bc
N_2S_0	4.00 g	6.33 de	5.67 e	5.67 e
N_2S_1	4.00 g	6.33 de	7.00 cd	6.67 bc
N_2S_2	4.66 e	6.67 cd	7.33 bc	6.00 de
N_2S_3	5.00 d	7.67 a	7.33 bc	7.00 ab
N_3S_0	3.67 h	6.33 de	7.33 bc	6.00 de
N_3S_1	4.00 g	6.33 de	7.67 b	6.33 cd
N_3S_2	4.33 f	6.67 cd	7.67 b	6.67 bc
N_3S_3	6.00 a	7.67 a	8.67 a	7.33 a
$LSD_{(0.05)}$	0.17	0.58	0.60	0.44
CV(%)	2.39	5.40	5.04	3.85

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

4.1.3 Effect of nitrogen and/ or sulphur on number of leaves plant^{-1}

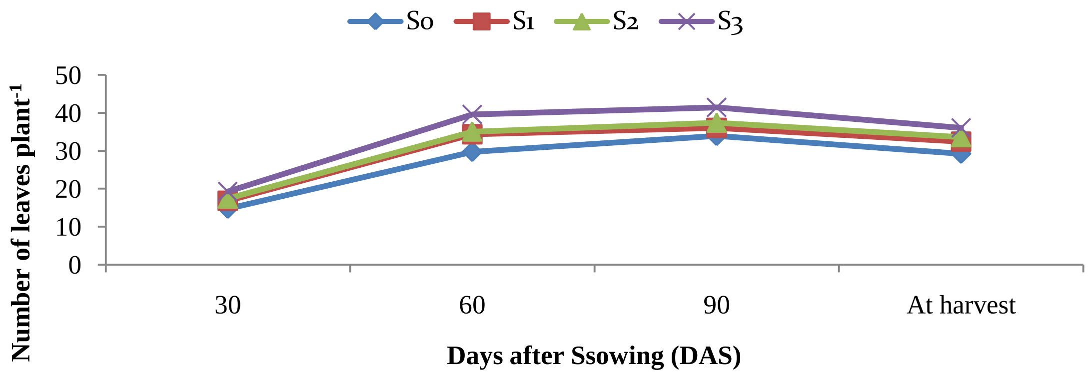
The number of leaves plant^{-1} increased gradually as the growth stage progressed up to harvest (Fig. 5). According to the experimental findings the highest number of leaves plant^{-1} (18.92, 38.59, 41.67 and 36.17 at 30, 60, 90 DAS, and at harvest, respectively) was observed in N_3 treatment. While the lowest number of leaves plant^{-1} (14.75, 31.75, 33.17 and 29.17 at 30, 60, 90 DAS, and at harvest, respectively) was observed in N_0 treatment. One of the effects of nitrogen on leaf number is that it can increase the number of leaves that a plant produces. This is because nitrogen is essential for leaf growth. When there is more nitrogen available, the leaves can grow larger and the plant can produce more leaves. The result was quite similar with the findings of Bijarnia *et al.* (2019) who reported that progressive increase in level of nitrogen up to 40 kg ha^{-1} significantly increased the number of leaves plant of sesame.



Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

Fig. 5. Effect of different doses of nitrogen on number of leaves plant^{-1} at different days after sowing of groundnut (LSD$_{(0.05)}$: 0.74, 1.49, 2.05 and 1.15 at 30, 60, 90 DAS and at harvest, respectively).

When applied different doses of sulphur fertilizer, the number of groundnut leaves plant^{-1} at various days after sowing varied significantly. (Fig. 6). Experimental result showed that the highest number of leaves plant^{-1} of groundnut (19.25, 39.59, 41.42 and 36.00 at 30, 60, 90 DAS, and at harvest respectively) was observed in S_3 treatment. While the lowest number of leaves plant^{-1} of groundnut (14.75, 29.75, 33.92 and 29.25) was observed in S_0 treatment at 30, 60, 90 DAS, and at harvest respectively, which was statistically similar with S_1 treatment (36.00) at 90 DAS. The difference in leaf number could be attributed to the efficient uptake and metabolism of available S. Many essential plant nutrients, particularly N, have a synergistic relationship with sulfur. In S-deficient soils, N uptake and absorption are limited, resulting in poor plant growth and development and a reduction in leaf number. The result was similar with the findings of Shaikh *et al.* (2019) who revealed that the application of RDF (50:25 NP kg ha^{-1}) with 30 kg sulphur ha^{-1} recorded higher mean functional leaves plant^{-1} compared to other treatments.



Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Fig. 6. Effect of doses of sulphur on number of leaves plant^{-1} at different days after sowing of groundnut (LSD$_{(0.05)}$: 0.75, 1.51, 2.10 and 1.19 at 30, 60, 90 DAS and at harvest, respectively).

The combined effect of nitrogen and sulfur doses revealed a significant difference in the number of leaves plant^{-1} of groundnut at various days after sowing. (Table 3). According to the experimental result, the highest number of leaves plant^{-1} (23.33, 42.67, 46.67 and 39.67 at 30, 60, 90 DAS, and at harvest, respectively) was observed in N_3S_3 treatment combination which was statistically similar with N_3S_2 (41.33) and N_2S_3 (40.67) at 60 DAS; with N_2S_3 (42.67 and 38.33) 90 DAS, and at harvest respectively. While the lowest number of leaves plant^{-1} (12.33, 24.67, 28.33 and 24.00 at 30, 60, 90 DAS, and at harvest, respectively) was observed in N_0S_0 treatment combination, which was statistically similar with N_1S_0 (13.33) treatment combination at 30 DAS.

Table 3. Combined effect of nitrogen and sulphur on number of leaves plant^{-1} at different days after sowing of groundnut

Treatment combination	Number of leaves plant^{-1} at			
	30 DAS	**60 DAS**	**90 DAS**	**Harvest**
N_0S_0	12.33 f	24.67 h	28.33 h	24.00 i
N_0S_1	13.33 f	32.67 e-g	33.33 g	30.00 gh
N_0S_2	16.00 de	33.00 ef	34.33 fg	31.00 fg
N_0S_3	17.33 cd	36.67 cd	36.67 d-g	31.67 e-g
N_1S_0	15.67 e	29.67 g	33.00 g	27.67 h
N_1S_1	17.67 bc	34.67 de	36.00 d-g	32.67 d-f
N_1S_2	16.00 de	33.67 d-f	35.33 e-g	32.67 d-f
N_1S_3	17.33 cd	38.33 bc	39.67 b-d	34.33 cd
N_2S_0	15.34 e	31.00 fg	35.67 d-g	31.67 e-g
N_2S_1	18.67 bc	33.33 ef	35.00 e-g	32.33 d-g
N_2S_2	18.67 bc	32.33 e-g	38.33 c-f	34.00 de
N_2S_3	19.00 b	40.67 ab	42.67 ab	38.33 ab
N_3S_0	15.67 e	33.67 d-f	38.67 b-e	33.67 de
N_3S_1	17.67 bc	36.67 cd	39.67 b-d	34.67 cd
N_3S_2	19.00 b	41.33 ab	41.67 bc	36.67 bc
N_3S_3	23.33 a	42.67 a	46.67 a	39.67 a
$LSD_{(0.05)}$	1.51	3.03	4.17	2.35
CV(%)	5.28	5.20	6.72	4.31

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

4.1.4 Effect of nitrogen and/ or sulphur on dry weight plant^{-1} (g)

Different doses of nitrogen fertilizer significantly influenced dry weight plant^{-1} of groundnut. The result revealed that the highest dry weight plant^{-1} (22.62 g) was observed in N_3 treatment, while the lowest dry weight plant^{-1} (16.64 g) was observed in N_0 treatment (Table 4). Similar results were given by Meena *et al* (2011) who reported that the application of 40 kg N ha^{-1} significantly enhanced dry matter accumulation as compared to the control. The application of higher dose of nitrogen possibly resulted in more dry matter accumulation due to increase in photosynthesis, more transport of metabolites to the sink and the development of extensive root system.

The experimental results revealed that dry weight plant^{-1} of groundnut was significantly influenced by different doses of sulphur fertilizers application (Table 5). Experimental results showed that the highest dry weight plant^{-1} of groundnut (21.33 g) was observed in S_3 treatment. Whereas the lowest dry weight plant^{-1} of groundnut (18.17 g) was observed in S_0 treatment. The improvement in dry matter accumulation per plant with increasing levels of sulphur might be due to an early and plentiful availability of sulphur leading to better nutritional environment in the root zone for growth and development. Therefore, overall growth with the application of sulphur in deficient soil could be ascribed to its vital role in several physiological and biochemical processes. Besides, sulphur is a constituent of number of amino acids which is essential for the growth and development of plant tissues. These findings accorded with the results of Sarkar *et al.* (2019).

At harvest, the dry weight of groundnut showed a significant difference as a result of the combined effects of nitrogen and sulfur doses (Table 6). The highest dry weight plant^{-1} (25.11 g) was observed in N_3S_3 treatment combination which was statistically similar with N_2S_3 (24.44 g) treatment combination. Whereas the lowest dry weight plant^{-1} (15.83 g) was observed in N_0S_0 treatment combination which was statistically similar with N_0S_1 (16.79 g), N_0S_2 (16.74 g), N_1S_0 (16.92 g), N_1S_1 (17.06 g) and N_1S_2 (17.14 g) treatment combinations.

4.1.5 Effect of nitrogen and/ or sulphur on number of nodules plant^{-1}

Application of different nitrogen fertilizer doses had shown significant effect on nodules number plant^{-1} of groundnut at harvest (Table 4). According to the experimental findings the N_3 treatment had the highest number of nodules plant^{-1} (75.18), while the N_0 treatment had the lowest number of nodules plant^{-1} (57.49). In the case of groundnut, nitrogen fertilization can help to increase the number and size of nodules on the roots. This is because nitrogen is essential for the growth and development of the bacteria that live in the nodules. Similar result also observed by Devi *et al*. (2022) who reported that increased application of nitrogen significantly influenced nodules number plant^{-1} of groundnut.

Table 4. Effect of doses of nitrogen on dry weight plant^{-1}, number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} of groundnut

Treatment	At harvest			Number of flowers plant^{-1}
	Dry weight plant^{-1} (g)	Number of nodules plant^{-1}	Dry weight of nodules plant^{-1} (g)	
N_0	16.64 d	57.49 c	0.219 c	8.84 b
N_1	17.43 c	59.62 c	0.228 c	9.33 b
N_2	21.65 b	72.27 b	0.276 b	10.75 a
N_3	22.62 a	75.18 a	0.287 a	11.42 a
$LSD_{(0.05)}$	0.72	2.39	0.009	0.72
CV(%)	3.69	3.62	3.75	7.22

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

The number of nodules plant^{-1} of groundnut was significantly influenced by different doses of sulphur fertilizers application (Table 5). Experimental result revealed that the highest number of nodules plant^{-1} of groundnut (71.33) was found in S_3 treatment, while the S_0 treatment had the lowest number of nodules plant^{-1} of groundnut (62.08). Similar result also observed by Yadav *et al.* (2018) who reported that the application of, 60 kg S ha^{-1} significantly influenced nodules number as well as dry weight of nodules plant^{-1} of groundnut. Sulfur is essential for nodulation. Sulfur deficiency reduced the number of nodules of groundnut plant. Nodules are the structures on legume roots that form a symbiotic relationship with bacteria called rhizobia. Rhizobia fix nitrogen from the air, which the legume plant can then use. Sulfur is a component of the proteins that are produced by rhizobia, and it is also needed for the formation of nodules.

The combined effects of nitrogen and sulfur doses resulted significant difference in groundnut nodules number plant^{-1} at harvest (Table 6). According to the experimental findings, the highest number of nodules plant^{-1} of groundnut (82.66) was observed in N_3S_3 treatment combination which was statistically similar with N_2S_3 (80.65) treatment combination. Whereas the lowest number of nodules plant^{-1} of groundnut (55.81) was observed in N_0S_0 treatment combination which was statistically similar with N_0S_1 (57.70), N_0S_2 (57.55), N_0S_3 (58.90), N_1S_0 (58.09), N_1S_1 (58.51) and N_1S_2 (58.76) treatment combination.

4.1.6 Effect of nitrogen and/ or sulphur on dry weight of nodules plant^{-1} (g)

The dry weight of nodules plant^{-1} of groundnut was significantly influenced by various doses of nitrogen fertilizer application (Table 4). The experimental findings show that the highest dry weight of nodules plant^{-1} (0.287 g) was found in the N_3 treatment, while the lowest dry weight of nodules plant^{-1} (0.219 g) was found in the N_0 treatment, which was statistically similar with N_1 (0.228 g) treatment.

The experimental results revealed that different sulphur fertilizer doses had shown significant effect on the dry weight of nodules plant^{-1} of groundnut (Table 5). The result reveals that the S_3 treatment had the highest dry weight of nodules plant^{-1} of groundnut (0.272 g). While the S_0 treatment had the lowest dry weight of nodules plant^{-1} of groundnut (0.237 g). The increase in dry weight of nodules per plant might be due to better root development with increasing levels of sulphur. These results were in close conformity with the findings of Debbarma (2016) who observed that application of 60 kg S ha^{-1} recorded significantly higher dry weight of nodules plant^{-1} of groundnut over 20 kg and 0 kg S ha^{-1}.

At harvest, the combined effects of nitrogen and sulfur doses significantly influenced on the dry weight of nodules plant^{-1} of groundnut (Table 6). According to the experimental findings, the highest dry weight of nodules plant^{-1} of groundnut (0.315 g) was observed in N_3S_3 treatment combination which was statistically similar with N_2S_3 (0.308 g) treatment combination. Whereas the lowest dry weight of nodules plant^{-1} of groundnut (0.213 g) was observed in N_0S_0 treatment combination which was statistically similar with N_0S_1

(0.220 g), N_0S_2 (0.219 g), N_0S_3 (0.225 g), N_1S_0 (0.222 g), N_1S_1 (0.223 g) and N_1S_2 (0.224 g) treatment combination.

4.1.7 Number of flowers plant^{-1}

Number of flowers plant^{-1} of groundnut was significantly influenced due to effect of different dose of nitrogen fertilizer application (Table 4). Experimental result showed that the N_3 treatment recorded the highest number of flowers plant^{-1} of groundnut (11.42) which was statistically similar with N_1 (10.75) treatment while the N_0 treatment recorded the lowest number of flowers plant^{-1} of groundnut (8.84) which was statistically similar with N_1 (9.33) treatment. The variation in the number of flowers plant^{-1} of groundnut could be attributed to an increased supply of nitrogen fertilizer, which is required in greater quantities for plant growth and development. Plant nutrients promote the development of the growth and reproductive phases, as well as protein synthesis, resulting in an increase in the number of flowers plant^{-1} of groundnut.

The effect of applying different doses of sulphur fertilizer had shown significant impact on the number of flowers on plant^{-1} of groundnut (Table 5). The results of the experiment show that the S_3 treatment recorded the highest number of groundnut flowers plant^{-1} (11.34), while the S_0 treatment recorded the lowest number of groundnut flowers plant^{-1} (9.00), which was statistically comparable to the S_1 (9.50) treatment. Sulphur deficiency reduced the size of floral displays, caused abnormal flower shapes, and changed the size and nutrient composition of pollen. Sulphur limitation reduced carotenoid synthesis, resulting in a clear reduction in flower color and visibility to pollinators, as well as a reduction in the number of flowers plant^{-1}.

Table 5. Effect of doses of sulphur on dry weight plant^{-1}, number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} of groundnut

Treatment	At harvest			Number of flowers plant^{-1}
	Dry weight plant^{-1} (g)	Number of nodules plant^{-1}	Dry weight of nodules plant^{-1} (g)	
S_0	18.17 c	62.08 c	0.237 c	9.00 c
S_1	19.09 b	64.62 b	0.247 b	9.50 c
S_2	19.73 b	66.53 b	0.253 b	10.50 b
S_3	21.33 a	71.33 a	0.272 a	11.34 a
$LSD_{(0.05)}$	0.64	2.35	0.008	0.63
CV(%)	3.90	4.23	4.09	7.47

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Combined effect of nitrogen and sulphur doses significantly influenced the number of flowers on plant^{-1} of groundnut (Table 6). According to the experimental findings, the highest number of flowers on plant^{-1} of groundnut (13.33) was observed in N_3S_3 treatment combination, which was statistically similar with N_2S_3 (12.67) treatment combination. While the lowest number of flowers on plant^{-1} of groundnut (7.67) was observed in N_0S_0 treatment combination, which was statistically similar with N_0S_1 (8.33) and N_1S_0 (8.33) treatment combination.

Table 6. Combined effect of nitrogen and sulphur on dry weight plant^{-1}, number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} of groundnut

Treatment combination	At harvest			Number of flowers plant^{-1}
	Dry weight plant^{-1} (g)	Number of nodules plant^{-1}	Dry weight of nodules plant^{-1} (g)	
N_0S_0	15.83 g	55.81 h	0.213 h	7.67 f
N_0S_1	16.79 fg	57.70 h	0.220 h	8.33 ef
N_0S_2	16.74 fg	57.55 h	0.219 h	9.67 cd
N_0S_3	17.19 f	58.90 gh	0.225 gh	9.67 cd
N_1S_0	16.92 fg	58.09 h	0.222 h	8.33 ef
N_1S_1	17.06 fg	58.51 gh	0.223 h	9.00 de
N_1S_2	17.14 fg	58.76 gh	0.224 gh	10.33 bc
N_1S_3	18.59 e	63.10 fg	0.241 fg	9.67 cd
N_2S_0	19.22 e	64.99 ef	0.248 ef	9.67 cd
N_2S_1	21.06 d	70.51 d	0.269 d	10.00 cd
N_2S_2	21.87 cd	72.94 cd	0.278 cd	10.67 bc
N_2S_3	24.44 ab	80.65 ab	0.308 ab	12.67 a
N_3S_0	20.70 d	69.43 de	0.265 de	10.33 bc
N_3S_1	21.47 d	71.74 d	0.274 d	10.67 bc
N_3S_2	23.18 bc	76.87 bc	0.293 bc	11.33 b
N_3S_3	25.11 a	82.66 a	0.315 a	13.33 a
$LSD_{(0.05)}$	1.32	4.71	0.017	1.31
CV(%)	3.90	4.23	4.09	7.47

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

4.2 Yield contributing parameters

4.2.1 Effect of nitrogen and/ or sulphur on number of pegs plant^{-1}

Number of pegs plant^{-1} of groundnut was significantly influenced due to effect of different dose of nitrogen fertilizer application (Table 7). Experimental results show that the N_3 treatment recorded the highest number of pegs plant^{-1} (29.03) while the N_0 treatment recorded the lowest number of pegs plant^{-1} (19.11).

Application of different doses of sulphur fertilizer had shown significant effect on the number of pegs plant^{-1} of groundnut (Table 8). The results of the experiment show that the S_3 treatment recorded the highest number of pegs plant^{-1} (26.47), while the S_0 treatment recorded the lowest number of pegs plant^{-1} (21.53).

The number of pegs plant^{-1} of groundnut significantly influenced due to the combined effect of nitrogen and sulphur doses (Table 9). According to the experimental findings, the highest number of pegs on plant^{-1} (33.33) was observed in N_3S_3 treatment combination. While the lowest number of pegs on plant^{-1} of groundnut (17.78) was observed in N_0S_0 treatment combination, which was statistically similar with N_0S_2 (18.55) and N_1S_0 (19.00) treatment combinations.

4.2.2 Effect of nitrogen and/ or sulphur on number of pods plant^{-1}

The different doses of nitrogen fertilizer application significantly affected the number of pods plant^{-1} of groundnut (Table 7). Experimental result revealed that the highest number of pods plant^{-1} (22.81) was found in N_3 treatment. Whereas the lowest number of pods plant^{-1} (13.75) was found in N_0 treatment. The result was similar with the findings of Iman and Ahmed (2014) who revealed that the application of 60 kg N ha^{-1} resulted significant effects on the number of pods plant^{-1} and gave the highest value of number of pods plant^{-1} of groundnut compared to other doses.

The number of pods plant^{-1} of groundnut was significantly influenced by the application of various doses of sulphur fertilizer (Table 8). According to the experimental results the highest number of pods plant^{-1} (21.03) was observed in the S_3 treatment. However. the S_0 treatment had the lowest number of pods plant^{-1} (14.56). This might be due to sulphur plays pivotal role in carbohydrate metabolism, energy transformation and storage and increase photosynthetic activity of plant. Hence, its favorable impacts on pods were also reported by Debbarma (2016) and Sarkar *et al.* (2019).

The combined effect of nitrogen and sulphur doses on pod number plant^{-1} of groundnut was found to be significant. (Table 9). The experimental results revealed that the N_3S_3 treatment combination recorded the highest pod number plant^{-1} of groundnut (27.78).

While the N_0S_0 treatment combination had the lowest pod number plant^{-1} of groundnut (11.33).

4.2.3 Effect of nitrogen and/ or sulphur on number of kernel pod^{-1}

The doses of nitrogen fertilizer application significantly affected the number of kernel pod^{-1} of groundnut (Table 7). Experimental result revealed that the highest number of kernel pod^{-1} of groundnut (1.82) was found in N_3 treatment. Whereas the lowest number of kernel pod^{-1} of groundnut (1.55) was found in N_0 treatment.

Table 7. Effect of doses of nitrogen on number of pegs plant^{-1}, pods plant^{-1}, kernel pod^{-1} and 100 seed weight of groundnut

Treatment	Pegs plant^{-1} (No.)	Pods plant^{-1} (No.)	Kernel pod^{-1} (No.)	100 seed weight (g)
N_0	19.11 d	13.75 d	1.55 d	39.94 d
N_1	21.42 c	16.05 c	1.62 c	49.35 c
N_2	24.86 b	19.14 b	1.75 b	55.95 b
N_3	29.03 a	22.81 a	1.82 a	60.86 a
$LSD_{(0.05)}$	1.43	0.70	0.05	1.44
CV(%)	6.08	3.94	3.53	2.80

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

The application of various doses of sulphur fertilizer had shown significant effect on the number of kernel pod^{-1} of groundnut (Table 12). According to the experimental findings, the S_3 treatment had the highest number of kernel pod^{-1} (1.80). The S_0 treatment, however, had the lowest number of kernel pod^{-1} of groundnut (1.60). Debbarma (2016) reported that the number of kernel pod^{-1} of groundnut was increased with increasing sulphur fertilizer levels. Sulphur, along with nitrogen, is very important for the production of amino acids. These amino acids are used in proteins. As sulphate, sulphur is also important for the water balance of the plant. Additionally, sulphur is active in the structure and metabolism of the plant and accelerates the production of chlorophyll. These help your plant grow through photosynthesis thereby influence dry matter production and ultimately increase number of kernel pod^{-1} of groundnut.

Groundnut kernel number pod^{-1} was found to be significantly affected by the combined effects of nitrogen and sulphur doses. (Table 13). The experimental results revealed that the N_3S_3 treatment combination recorded the highest number of kernel pod^{-1} (2.00). While the N_0S_0 treatment combination had the lowest number of kernel pod^{-1} (1.49) which was statistically similar with N_0S_1 (1.52), N_0S_2 (1.48) and N_1S_0 (1.53) treatment combination.

4.2.4 Effect of nitrogen and/ or sulphur on 100 seed weight (g)

Application of different doses of nitrogen significantly influenced 100 seed weight of groundnut (Table 7). According to the experimental findings, the highest 100 seed weight of groundnut (60.86 g) was observed in N_3 treatment. While the lowest 100 seed weight of groundnut (39.94 g) was observed in N_0 treatment. The growth, development, maturity and yield of the crop are directly related to the amount of nutrients that is made available to the crop during its growth period without wastage to the environment. The enhancement in soil nutrient content with increasing N rate may have favoured the chemical composition of the soil for better nutrient utilization result in increased seed weight of groundnut. The result was similar with the findings of El-Habbasha *et al* (2013) who reported that the increase in N levels from 30 to 40 kg N ha^{-1} significantly increased 100-seed weight of groundnut crop.

Different doses of sulphur applications had shown significant effect on the 100 seed weight of groundnut (Table 8). According to the experimental results, the S_3 treatment had the highest 100 seed weight of groundnuts (55.58 g). While the S_0 treatment had the lowest 100 seed weight of groundnut (47.44 g). The reason behind that availability of sulphur helps in improving photosynthetic activity, seed formation along with synthesis of amino acids, chlorophyll, proteins and stimulating nodulation might be attributed to increase total biomass production that was directly reflected in increment in 100 seed weight of groundnut. Rao *et al.* (2013) reported that application of 45 kg S ha^{-1} through gypsum recorded the highest 100-pod weight, 100- kernel weight of groundnut.

Table 8. Effect of doses of sulphur on number of pegs $plant^{-1}$, pods $plant^{-1}$, kernel pod^{-1} and 100 seed weight of groundnut

Treatment	Pegs $plant^{-1}$ (No.)	Pods $plant^{-1}$ (No.)	Kernel pod^{-1} (No.)	100 seed weight (g)
S_0	21.53 c	14.56 d	1.60 c	47.44 c
S_1	22.84 b	17.33 c	1.65 bc	51.28 b
S_2	23.58 b	18.84 b	1.69 b	51.79 b
S_3	26.47 a	21.03 a	1.80 a	55.58 a
$LSD_{(0.05)}$	0.83	0.67	0.05	1.46
CV(%)	4.19	4.41	4.02	3.43

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Groundnut 100 seed weight was found to be significantly affected by the combined effects of nitrogen and sulphur doses. (Table 9). The experimental results revealed that the N_3S_3 treatment combination recorded the highest 100 seed weight of groundnut (65.62 g). While the N_0S_0 treatment combination recorded the lowest 100 seed weight of groundnut (35.59 g).

Table 9. Combined effect of nitrogen and sulphur on number of pegs plant^{-1}, pods plant^{-1}, kernel pod^{-1} and 100 seed weight of groundnut

Treatment combination	Pegs plant^{-1} (No.)	Pods plant^{-1} (No.)	Kernel pod^{-1} (No.)	100-seed weight (g)
N_0S_0	17.78 k	11.33 j	1.49 f	35.59 l
N_0S_1	19.67 ij	14.11 hi	1.52 ef	40.52 jk
N_0S_2	18.55 jk	13.67 i	1.48 f	39.08 k
N_0S_3	20.44 hi	15.89 fg	1.70 cd	44.55 i
N_1S_0	19.00 i-k	13.56 i	1.53 ef	42.72 ij
N_1S_1	20.34 ij	15.33 gh	1.62 de	48.76 h
N_1S_2	22.11 gh	17.11 ef	1.67 cd	52.40 g
N_1S_3	24.22 ef	18.22 e	1.67 cd	53.53 fg
N_2S_0	23.00 fg	15.89 fg	1.68 cd	53.83 fg
N_2S_1	23.22 fg	17.67 e	1.72 b-d	56.28 d-f
N_2S_2	25.33 de	20.78 d	1.77 bc	55.08 e-g
N_2S_3	27.89 bc	22.22 c	1.83 b	58.62 b-d
N_3S_0	26.33 cd	17.44 e	1.70 cd	57.64 c-e
N_3S_1	28.11 b	22.22 c	1.73 b-d	59.55bc
N_3S_2	28.33 b	23.78 b	1.83 b	60.62 b
N_3S_3	33.33 a	27.78 a	2.00 a	65.62 a
$LSD_{(0.05)}$	1.66	1.34	0.11	2.94
CV(%)	4.19	4.41	4.02	3.43

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

4.3 Yield

4.3.1 Effect of nitrogen and/ or sulphur on pod yield (t ha^{-1})

The effect of different doses of nitrogen fertilizer application significantly affected the pod yield of groundnut (Table 10). Experimental result showed that the highest pod yield of groundnut (2.06 t ha^{-1}) was found in N_3 treatment. While the lowest pod yield of groundnut (1.44 t ha^{-1}) was found in N_0 treatment which was statistically similar with N_1 (1.51 t ha^{-1}) treatment. The present study indicated that pod yield was considerably improved by increasing the nitrogen level of the soil. This amelioration in pod yield is a result of an increase in the main yield components, especially number of pods plant^{-1}. Ali and Seyyed (2010) reported that applying 60 kg N ha^{-1} resulted in considerably greater pod production (2314 kg ha^{-1}) and kernel yield (1378 kg ha^{-1}) of groundnut.

Different doses of sulphur applications had shown significant effect on the pod yield of groundnut (Table 11). According to the experimental results, the S_3 treatment had the highest pod yield of groundnut (1.95 t ha^{-1}). While the S_0 treatment had the lowest pod yield of groundnut (1.58 t ha^{-1}). The reason behind that availability of sulphur helps in improving photosynthetic activity, seed formation along with synthesis of amino acids, chlorophyll, proteins and stimulating nodulation might be attributed to increase total biomass production that was directly reflected in increment in pod yield of groundnut. Rao *et al.* (2013) reported that application of 45 kg S ha^{-1} through gypsum recorded the highest pod yield of groundnut.

Pod yield of groundnut was found to be significantly affected by the combined effects of nitrogen and sulphur doses. (Table 12). The experimental results revealed that the N_3S_3 treatment combination recorded the highest pod yield of groundnut (2.37 t ha^{-1}) which was statistically similar with the N_2S_3 (2.28 t ha^{-1}) treatment combination. While the N_0S_0 treatment combination recorded the lowest pod yield of groundnut (1.37 t ha^{-1}) which was statistically similar with N_0S_1 (1.45 t ha^{-1}), N_0S_2 (1.44 t ha^{-1}), N_0S_3 (1.51 t ha^{-1}), N_1S_0 (1.44 t ha^{-1}),N_1S_1 (1.47 t ha^{-1})and N_1S_2 (1.48 t ha^{-1}) treatment combination.

4.3.2 Effect of nitrogen and/ or sulphur on kernel yield (t ha^{-1})

The groundnut kernel yield was significantly influenced by the application of various nitrogen fertilizer doses (Table 10). According to experimental findings, N_3 treatment recorded the highest kernel yield of groundnuts (1.65 t ha^{-1}). The N_0 treatment had the lowest kernel yield of groundnuts (1.06 t ha^{-1}). Nitrogen fertilizer is an important factor in achieving better growth and development of vegetative and reproductive organs of groundnut and with increases fertilizer dose increases of photosynthesis rate and photosynthetic matters production, kernel yield and yield components of groundnut. Similar result also observed by Chirwa *et al.* (2017) who reported that the application of 20 kg N ha^{-1} resulted in an increase in pod yield, kernel yield, and N uptake by groundnut plants when compared to the control.

The groundnut kernel yield had been significantly affected by various sulphur application doses (Table 11). The S_3 treatment had the highest kernel yield of groundnut (1.56 t ha^{-1})

while the S_0 treatment had the lowest kernel yield of groundnut (1.12 t ha^{-1}). The reason behind that accelerated nutrient uptake with increased levels of sulphur helped the plant to put under optimum growth. The stimulatory effect of sulphur on photosynthetic activity, seed formation along with synthesis of amino acids, chlorophyll, proteins and stimulating nodulation might be attributed to higher growth and development of plant tissues per day thereby influence kernel yield of groundnuts. Pancholi *et al.* (2017) reported that application of sulphur at 60 kg^{-1} ha gave the highest kernel yield as compare to preceding levels.

Kernel yield of groundnut was found to be significantly affected by the combined effects of nitrogen and sulphur doses (Table 12). The experimental results revealed that the N_3S_3 treatment combination recorded the highest kernel yield of groundnut (1.95 t ha^{-1}). While the N_0S_0 treatment combination recorded the lowest kernel yield of groundnut (0.97 t ha^{-1}) which was statistically similar with N_0S_1 (1.03 t ha^{-1}), N_0S_2 (1.06 t ha^{-1}), N_1S_0 (1.03 t ha^{-1}) and N_1S_1 (1.07 t ha^{-1}) treatment combination.

4.3.3 Effect of nitrogen and/ or sulphur on haulm yield (t ha^{-1})

Effect of nitrogen

The application of various nitrogen fertilizer doses had shown significant impact on the haulm yield of groundnut (Table 10). The results of the experiment showed that the N_3 treatment recorded the highest haulm yield of groundnut (2.95 t ha^{-1}). While the lowest haulm yield of groundnut (2.27 t ha^{-1}) was observed in the N_0 treatment. The increased supply of N and their higher uptake by plants might have stimulated the rate of various physiological processes in plant and led to increased growth and yield parameters and resulted in increased pod and haulm yields. The result was similar with the findings of Meena *et al.* (2011) who reported that, when compared to control and 20 kg N ha^{-1}, the application of 40 kg N ha^{-1} significantly improved yield parameters such as haulm yield, of groundnut.

Table 10. Effect of doses of nitrogen on pod yield, kernel yield, haulm yield, biological yield, harvest index and shelling % of groundnut

Treatments	Pod yield (t ha^{-1})	Kernel yield (t ha^{-1})	Haulm yield (t ha^{-1})	Biologic al yield (t ha^{-1})	Harvest index	Shelling %
N_0	1.44 c	1.06 d	2.27 d	3.72 d	38.82 c	73.56 c
N_1	1.51 c	1.13 c	2.37 c	3.87 c	38.91 c	74.53 bc
N_2	1.93 b	1.46 b	2.88 b	4.81 b	40.09 b	75.31 b
N_3	2.06 a	1.65 a	2.95 a	5.03 a	41.22 a	79.03 a
$LSD_{(0.05)}$	0.07	0.05	0.04	0.09	0.95	1.55
CV(%)	4.31	4.49	2.21	2.17	2.41	2.06

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

The application of different doses of sulphur fertilizer had shown significant impact on the haulm yield of groundnut (Table 11). The results of the experiment showed that the S_3 treatment recorded the highest haulm yield of groundnut (2.79 t ha^{-1}). While the lowest haulm yield of groundnut (2.48 t ha^{-1}) was observed in the S_0 treatment. It might be due to cell enlargement, elongation and division were increased by sulphur fertilization resulting in overall improvement in plant tissues associated with quicker and uniform vegetative growth of the crop. The result was similar with the findings of Patel *et al.* (2018) who that the yield and quality parameters of groundnut were improved with increased levels of sulphur.

The combined effects of nitrogen and sulphur doses on groundnut haulm yield were found to be significantly affected. (Table 12). The experimental results revealed that the N_3S_3 treatment combination recorded the highest haulm yield of groundnut (3.21 t ha^{-1}) which was statistically similar with the N_2S_3 (3.15 t ha^{-1}) treatment combination. While the N_0S_0 treatment combination recorded the lowest haulm yield of groundnut (2.22 t ha^{-1}) which was statistically similar with N_0S_1 (2.28 t ha^{-1}), N_0S_2 (2.28 t ha^{-1}), N_0S_3 (2.31 t ha^{-1}), N_1S_0 (2.32 t ha^{-1}), N_1S_1 (2.32 t ha^{-1}) and N_1S_1 (2.33 t ha^{-1}) treatment combination.

4.3.4 Effect of nitrogen and/ or sulphur on biological yield (t ha^{-1})

The biological yield of groundnut varied significantly due to application of different doses of nitrogen fertilizer (Table 10). According to the experimental findings, the highest biological yield of groundnut (5.03 t ha^{-1}) was observed in N_3 treatment, while the lowest biological yield of groundnut (3.72 t ha^{-1}) was observed in N_0 treatment.

Due to the use of various sulphur fertilizer doses, the biological yield of groundnuts varied significantly (Table 11). The experimental results showed that the S_3 treatment had the highest biological yield of groundnut (4.74 t ha^{-1}), while the s_0 treatment had the lowest biological yield of groundnut (4.06 t ha^{-1}). It might be due to cell enlargement, elongation and division were increased by sulphur fertilization resulting in overall improvement in plant tissues associated with quicker and uniform vegetative growth of the crop. The result was quite similar with the findings of Jamal *et al.* (2006) who reported that the application of 20 kg sulphur + 43.5 kg nitrogen ha^{-1} recorded significant the highest biological yield (9333 kg ha^{-1}) of groundnut compared to other treatments.

Application of different doses of nitrogen along with sulphur significantly influenced biological yield of groundnuts (Table 12). According to the experimental findings, the N_3S_3 treatment combination recorded the highest biological yield of groundnut (5.58 t ha^{-1}) which was statistically similar with the N_2S_3 (5.43 t ha^{-1}) treatment combination. While the N_0S_0 treatment combination recorded the lowest biological yield of groundnut (3.59 t ha^{-1}) which was statistically similar with N_0S_1 (3.73 t ha^{-1}), N_0S_2 (3.72 t ha^{-1}) and N_1S_0 (3.76 t ha^{-1}) treatment combination.

4.3.5 Effect of nitrogen and/ or sulphur on harvest index (%)

Harvest index (%) of groundnut showed significant variation due to effect of different nitrogen dose (Table 10) From the experimental result it was revealed that the highest harvest index (41.22 %) was recorded in N_3 treatment. Whereas the lowest harvest index (38.82 %) was recorded in N_0 treatment which was statistically similar with N_1 (38.91 %) treatment. Different nitrogen doses influence pod, kernel, and biological yield which ultimately impact on harvest index.

The harvest index of groundnut had been significantly influenced by the application of various sulphur fertilizer doses (Table 11). The experimental findings revealed that the S_3 treatment had the highest harvest index of groundnut (40.93 %). While the S_0 treatment had the lowest harvest index of groundnut (38.73 %) which was statistically similar with S_1 (39.62 %) treatment.

Combined effect of nitrogen and sulphur dose had shown significant variation in respect of harvest index (%) of groundnut (Table12). Experimental result showed that the highest harvest index (42.47 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_3S_2 (41.75 %), N_3S_1 (41.30 %), and N_2S_3 (41.99 %) treatment combination. Whereas the lowest harvest index (38.16 %) was recorded in N_0S_0 treatment combination which was statistically similar with all other treatment except N_3S_2 (41.75 %), N_3S_1 (41.30 %), and N_2S_3 (41.99 %) treatment combination.

4.3.6 Effect of nitrogen and/ or sulphur on shelling %

Shelling (%) of groundnut showed significant variation due to effect of different nitrogen dose ((Table 10) From the experimental result it was revealed that the highest shelling percentage (79.03 %) was recorded in N_3 treatment. Whereas the lowest shelling percentage (73.56 %) was recorded in N_0 treatment which was statistically similar with N_1 (74.53 %) treatment. The result was similar with the findings of Gohari and Niyaki (2010), who reported that the application of 60 kg N ha^{-1} resulted in a higher shelling percentage of peanut than control and 30 kg N ha^{-1}.

The shelling percentage of groundnut had been significantly influenced by the application of various sulphur fertilizer doses (Table 11). The experimental findings revealed that the S_3 treatment had the highest shelling percentage of groundnut (79.59 %). While the S_0 treatment had the lowest shelling percentage of groundnut (71.22 %). Shelling percentage is one of the most essential factors relating to the thickness of the shell, kernel development, and flowering pattern during the plant's growth because the final yield is determined by kernels. Gashti *et al* (2012) reported that the enhancement in shelling % of peanut with gypsum application could be attributed to the sulphur and calcium, which may have aided to the plant's ability to transmit food supplies to the shell at a sufficient rate for optimal utilization.

Table 11. Effect of doses of sulphur on pod yield, kernel yield, haulm yield, biological yield, harvest index and shelling % of groundnut

Treatment	Pod yield ($t\ ha^{-1}$)	Kernel yield ($t\ ha^{-1}$)	Haulm yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index	Shelling %
S_0	1.58 c	1.12 d	2.48 d	4.06 d	38.73 c	71.22 d
S_1	1.69 b	1.26 c	2.56 c	4.24 c	39.62 bc	74.37 c
S_2	1.75 b	1.36 b	2.64 b	4.39 b	39.76 b	77.26 b
S_3	1.95 a	1.56 a	2.79 a	4.74 a	40.93 a	79.59 a
$LSD_{(0.05)}$	0.06	0.04	0.05	0.08	0.94	1.41
CV(%)	5.18	4.22	2.70	2.37	2.81	2.22

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Combined effect of nitrogen and sulphur dose had shown significant variation in respect of shelling percentage of groundnut (Table 12). Experimental result showed that the highest shelling percentage of groundnut (82.28 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_3S_2 (81.86 %), N_3S_1 (80.71 %), and N_2S_3 (79.82 %) treatment combination. Whereas the lowest shelling percentage of groundnut (70.80 %) was recorded in N_0S_0 treatment combination which was statistically similar with all other treatment except N_0S_1 (71.00 %), N_0S_2 (73.61 %), N_1S_0 (71.53 %), N_1S_1 (72.79 %), N_2S_0 (71.26 %) and N_2S_1 (72.97 %), treatment combination.

Table 12. Combined effect of nitrogen and sulphur on pod yield, kernel yield, haulm yield, biological yield, harvest index and shelling % of groundnut

Treatment combination	Pod yield (t ha^{-1})	Kernel yield (t ha^{-1})	Haulm yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index	Shelling %
N_0S_0	1.37 h	0.97 h	2.22 f	3.59 g	38.16 c	70.80 f
N_0S_1	1.45 h	1.03 gh	2.28 f	3.73 fg	38.87 c	71.00 f
N_0S_2	1.44 h	1.06 gh	2.28 f	3.72 fg	38.71 c	73.61 ef
N_0S_3	1.51 gh	1.19 ef	2.31 f	3.82 f	39.53 bc	78.81 b-d
N_1S_0	1.44 h	1.03 h	2.32 f	3.76 fg	38.30 c	71.53 f
N_1S_1	1.47 h	1.07 gh	2.32 f	3.79 f	38.79 c	72.79 f
N_1S_2	1.48 h	1.13 fg	2.33 f	3.81 f	38.86 c	76.35 de
N_1S_3	1.64 fg	1.27 de	2.49 e	4.13 e	39.71 bc	77.44 cd
N_2S_0	1.67 ef	1.19 ef	2.60 e	4.27 e	39.11 c	71.26 f
N_2S_1	1.85 cd	1.35 d	2.83 cd	4.68 d	39.53 bc	72.97 f
N_2S_2	1.93 cd	1.49 c	2.93 bc	4.86 c	39.71 bc	77.20 cd
N_2S_3	2.28 ab	1.82 b	3.15 a	5.43 a	41.99 a	79.82 a-c
N_3S_0	1.81 de	1.29 de	2.79 d	4.60 d	39.35 c	71.27 f
N_3S_1	1.97 c	1.59 c	2.80 d	4.77 cd	41.30 ab	80.71 ab
N_3S_2	2.15 b	1.76 b	3.00 b	5.15 b	41.75 a	81.86 a
N_3S_3	2.37 a	1.95 a	3.21 a	5.58 a	42.47 a	82.28 a
$LSD_{(0.05)}$	0.15	0.10	0.11	0.17	1.88	2.89
CV(%)	5.18	4.22	2.70	2.37	2.81	2.22

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

4.4 Quality parameters

4.4.1 Effect of nitrogen and/ or sulphur on seed protein content (%)

Different nitrogen doses significantly influenced seed protein content of groundnut (Table 13). According to the experimental findings, the highest seed protein content of groundnut (27.14 %) was observed in N_3 treatment while the lowest seed protein content of groundnut (19.33 %) was observed in N_0 treatment, which was statistically similar with N_1 (19.76 %) treatment. The result was similar with the findings of Hasan *et al*. (2021) who reported that the protein, fibre, Mg and amino acid content of bambara groundnut increased with increased nitrogen fertilizer application.

Table 13. Effect of doses of nitrogen on seed protein content, oil content, seed nitrogen content, seed sulphur content and seed germination percentage of groundnut

Treatment	Seed protein content (%)	Seed oil content (%)	Seed nitrogen content %	Seed sulphur content %	Seed germination (%)
N_0	19.33 c	34.43 d	3.09 c	0.17 d	80.92 c
N_1	19.76 c	39.43 c	3.16 c	0.19 c	81.67 c
N_2	22.75 b	44.91 b	3.64 b	0.24 b	85.67 b
N_3	27.14 a	49.59 a	4.34 a	0.27 a	90.58 a
$LSD_{(0.05)}$	1.74	2.49	0.13	0.01	1.18
CV(%)	7.87	5.94	3.70	5.55	3.41

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1} and N_3: 13.8 kg Nitrogen ha^{-1}.

Application of different doses of sulphur significantly influenced groundnut seed protein content (Table 14). According to the experimental results, the highest groundnut seed protein content (24.79 %) was observed in the S_3 treatment, while the lowest groundnut seed protein content (19.22%) was observed in the S_0 treatment. It might be due to sulphur is a main constituent of sulphur containing amino acids which are the building blocks of protein. Another reason behind that sulphur increase nitrogen uptake and content which is directly related to protein content. The present findings are in close conformity with the results of Pandey *et al*. (2018) who reported that the protein content and oil content in groundnut kernels increased significantly with Sulphur fertilization and maximum value of protein (27.09%) content and oil content (49.72%) were observed with application of sulphur @ 40 kg ha^{-1}.

The combined effect of nitrogen and sulfur doses resulted in significant variation in groundnut seed protein content (Table 15). Experimental result showed that the highest seed protein content of groundnut (29.56 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_3S_2 (28.31 %) and N_3S_1 (27.75 %) treatment combination. Whereas the lowest seed protein content of groundnut (15.63 %) was recorded in N_0S_0 treatment combination which was statistically similar with N_1S_0 (17.50 %) treatment combination.

4.4.2 Effect of nitrogen and/ or sulphur on seed oil content (%)

Application of different nitrogen doses had shown significant effect on groundnut seed oil content (Table 13). According to the experimental findings, the N_3 treatment had the highest seed oil content of groundnut (49.59 %), while the N_0 treatment had the lowest seed oil content of groundnut (34.43%).

The seed oil content of groundnut was significantly influenced by different sulphur doses (Table 14). The S_3 treatment had the highest seed oil content of groundnut (46.16 %), while the S_0 treatment had the lowest seed oil content of groundnut (38.24%). The reason behind that sulphur plays a vital role in synthesis of essential amino acids like cysteine, methionine and certain vitamin like thymine, biotin along with the formation of ferodoxin that act as an electron carrier in the photosynthesis process and chlorophyll which required for the oil production. Similar findings were also reported by Patel *et al.* (2018).

Table 14. Effect of doses of sulphur on seed protein content, oil content, seed nitrogen content, seed sulphur content and seed germination percentage of groundnut

Treatment	Seed protein content (%)	Seed oil content (%)	Seed nitrogen content %	Seed sulphur content %	Seed germination (%)
S_0	19.22 d	38.24 d	3.08 d	0.20 c	79.17 c
S_1	21.89 c	40.68 c	3.50 c	0.22 b	83.75 b
S_2	23.06 b	43.27 b	3.69 b	0.22 b	84.50 b
S_3	24.79 a	46.16 a	3.97 a	0.24 a	91.42 a
$LSD_{(0.05)}$	0.99	1.83	0.11	0.01	0.94
CV(%)	5.31	5.18	4.50	6.61	3.32

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

Seed oil content of groundnut varied significantly as a result of the combined effect of nitrogen and sulfur doses. (Table 15). Experimental result showed that the highest seed oil content of groundnut (51.62 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_3S_2 (50.55 %) and N_3S_1 (48.62 %) treatment combination. Whereas the lowest seed oil content of groundnut (29.59 %) was recorded in N_0S_0

treatment combination which was statistically similar with N_0S_1 (31.08 %) and N_0S_1 (32.72 %) treatment combination.

4.4.3 Effect of nitrogen and/ or sulphur on seed nitrogen content (%)

Different nitrogen doses significantly influenced groundnut seed nitrogen content (Table 13). According to the experimental findings, the highest seed nitrogen content of groundnut (4.34 %) was observed in N_3 treatment while the lowest seed nitrogen content of groundnut (3.09 %) was observed in N_0 treatment, which was statistically similar with N_1 (3.16 %) treatment.

The nitrogen content of groundnut seeds was significantly influenced by different sulphur doses (Table 14). Experimental result showed that the S_3 treatment had the highest groundnut seed nitrogen content (3.97 %), while the S_0 treatment had the lowest groundnut seed nitrogen content (3.08 %). This increment in nitrogen content in kernel might be due to favorable effect sulphur on availability of nitrogen.

Groundnut seed nitrogen content varied significantly as a result of the combined effect of nitrogen and sulphur doses. (Table 15). Experimental result showed that the highest seed nitrogen content of groundnut (4.73 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_3S_2 (4.53 %) treatment combination. Whereas the lowest seed nitrogen content of groundnut (2.50 %) was recorded in N_0S_0 treatment combination.

4.4.4 Seed sulphur content (%)

Application of different nitrogen doses had shown significant effect on groundnut seed sulphur content (Table 13). According to the experimental findings, the N_3 treatment had the highest seed sulphur content of groundnut (0.27 %), while the N_0 treatment had the lowest seed sulphur content of groundnut (0.17%).

The seed sulphur content of groundnut was significantly influenced by different sulphur doses (Table 14). The S_3 treatment had the highest seed sulphur content of groundnut

(0.24 %), while the S_0 treatment had the lowest seed sulphur content of groundnut (0.20%).

Groundnut seed sulphur content varied significantly as a result of the combined effect of nitrogen and sulphur doses. (Table 15). Experimental result showed that the highest seed sulphur content of groundnut (0.29 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_3S_2 (0.27 %) and N_3S_1 (0.27 %) treatment combination. Whereas the lowest seed sulphur content of groundnut (0.15 %) was recorded in N_0S_0 treatment combination which was statistically similar with N_0S_1 (0.17 %) and N_0S_2 (0.17 %) treatment combination.

4.4.5 Effect of nitrogen and/ or sulphur on seed germination %

The application of different of doses of nitrogen on seed germination percentage of groundnut was found to be significant. (Table 13). Experimental result showed that the highest seed germination percentage (90.58 %) was observed in N_3 treatment. While the N_0 treatment had the lowest seed germination percentage (80.92 %) which was statistically similar with N_1 (81.67 %) treatment.

The seed germination percentage of groundnut was significantly influenced by different sulphur doses (Table 14). The S_3 treatment had the highest seed germination percentage of groundnut (91.42 %), while the S_0 treatment had the lowest seed germination percentage of groundnut (79.17 %).

Groundnut seed germination percentage varied significantly as a result of the combined effect of nitrogen and sulphur doses. (Table 15). Experimental result showed that the highest seed germination percentage (96.33 %) was recorded in N_3S_3 treatment combination which was statistically similar with N_2S_3 (94.33 %) treatment combination. Whereas the lowest seed germination percentage (78.00 %) was recorded in N_0S_0 treatment combination which was statistically similar with N_0S_1 (79.00 %), N_0S_2 (78.67 %), N_1S_0 (78.67 %), N_1S_2 (79.33 %) and N_2S_0 (79.00 %) treatment combination.

Table 15. Combined effect of nitrogen and sulphur on seed protein content, oil content, seed nitrogen content, seed sulphur content and seed germination percentage of groundnut

Treatment combinations	Seed protein content (%)	Seed oil content (%)	Seed nitrogen content %	Seed sulphur content %	Seed germination (%)
N_0S_0	15.63 g	29.59 i	2.50 i	0.15 i	78.00 g
N_0S_1	19.19 ef	31.08 hi	3.07 fg	0.17 hi	79.00 fg
N_0S_2	19.81 ef	33.52 h	3.17 fg	0.17 hi	78.67 g
N_0S_3	22.69 b-d	43.53 d-f	3.63 d	0.19 gh	88.00 d
N_1S_0	17.50 fg	32.72 hi	2.80 h	0.18 gh	78.67 g
N_1S_1	18.32 f	38.76 g	2.93 gh	0.19 gh	81.67 e
N_1S_2	20.82 de	42.40 fg	3.33 ef	0.20 fg	79.33 fg
N_1S_3	22.38 b-d	43.83 d-f	3.58 de	0.22 ef	87.00 d
N_2S_0	20.81 de	43.08 ef	3.33 ef	0.23 de	79.00 fg
N_2S_1	22.31 cd	44.28 d-f	3.57 de	0.24 c-e	82.33 e
N_2S_2	23.31 bc	46.62 b-e	3.73 cd	0.25 b-d	87.00 d
N_2S_3	24.56 b	45.64 c-f	3.93 c	0.26 bc	94.33 ab
N_3S_0	22.94 b-d	47.55 b-d	3.67 cd	0.25 b-d	81.00 ef
N_3S_1	27.75 a	48.62 a-c	4.44 b	0.27 ab	92.00 c
N_3S_2	28.31 a	50.55 ab	4.53 ab	0.27 ab	93.00 bc
N_3S_3	29.56 a	51.62 a	4.73 a	0.29 a	96.33 a
$LSD_{(0.05)}$	2.44	4.03	0.26	0.24	2.01
CV(%)	5.31	5.18	4.50	6.61	3.32

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, N_0: 0 kg Nitrogen ha^{-1}, N_1: 9.2 kg Nitrogen ha^{-1}, N_2: 11.5 kg Nitrogen ha^{-1}, N_3: 13.8 kg Nitrogen ha^{-1}, S_0: 0 kg Sulphur ha^{-1}, S_1: 45 kg Sulphur ha^{-1}, S_2: 54 kg Sulphur ha^{-1} and S_3: 63 kg Sulphur ha^{-1}.

CHAPTER V

SUMMARY AND CONCLUSION

A field experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during the period from February to August 2021 in Kharif season, to study the effect of nitrogen and sulphur on yield and seed quality of groundnut. The experiment consisted of two factors, and followed split plot design with three replications. Factor A: Different levels of nitrogen (4) *viz;* N_0: 0 kg Urea ha^{-1}/0 kg Nitrogen ha^{-1}, N_1: 20 kg Urea ha^{-1} /9.2 kg Nitrogen ha^{-1}, N_2: 25 kg Urea ha^{-1}/11.5 kg Nitrogen ha^{-1} and N_3: 30 kg Urea ha^{-1}/13.8 kg Nitrogen ha^{-1} and Factor B: Different levels of sulphur (4) *viz;* S_0: 0 kg Gypsum ha^{-1} /0 kg Sulphur ha^{-1}, S_1: 250 kg Gypsum ha^{-1}/45 kg Sulphur ha^{-1}, S_2: 300 kg Gypsum ha^{-1} /54 kg Sulphur ha^{-1} and S_3: 350 kg Gypsum ha^{-1}/63 kg Sulphur ha^{-1}. For the purpose of evaluating the experimental outcomes, data on various parameters were evaluated. The analysis of various parameter data revealed significant differences in groundnut growth, yield, and quality characteristics as a result of nitrogen and sulphur application doses and their treatment combination.

In case of different levels of nitrogen application, the growth parameters *i.e*. plant height, number of branches plant^{-1}, number of leaves plant^{-1}, dry weight plant^{-1} (g), number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} varied due to different levels of nitrogen fertilizer application. However, in terms of yield contributing characteristics yield and quality characteristics of groundnut the N_3 treatment performed well and recorded the highest number of pegs plant^{-1} of groundnut (29.03), pods plant^{-1} (22.81), kernel pod^{-1} (1.82), 100 seed weight (60.86 g), pod yield (2.06 t ha^{-1}), kernel yield (1.65 t ha^{-1}), haulm yield (2.95 t ha^{-1}), biological yield (5.03 t ha^{-1}), harvest index (41.22 %), shelling percentage (79.03 %), seed protein content (27.14 %), seed oil content (49.59 %), seed nitrogen content (4.34 %), seed sulphur content (0.27 %) and seed germination percentage (90.58 %). While the N_0 treatment recorded the lowest number of pegs plant^{-1} of groundnut (19.11), pods plant^{-1} (13.75), kernel pod^{-1} (1.55), 100 seed weight (39.94 g), pod yield (1.44 t ha^{-1}), kernel yield (1.06 t ha^{-1}), haulm yield (2.27 t ha^{-1}), biological yield (3.72 t ha^{-1}), harvest index (38.82 %), shelling percentage (73.56 %), seed protein content (19.33 %), seed oil content (34.43%), seed nitrogen content (3.09 %), seed sulphur content (0.17%), seed germination percentage (80.92 %).

The growth parameters, such as plant height, number of branches plant^{-1}, number of leaves plant^{-1}, dry weight plant^{-1} (g), number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} varied due to different levels of nitrogen fertilizer application varied for different levels of sulphur fertilizer application. However, in terms of yield contributing characteristics yield and quality characteristics of groundnut the highest number of pegs plant^{-1} (26.47), pods plant^{-1} (21.03), kernel pod^{-1} (1.80), 100 seed weight (55.58 g), pod yield (1.95 t ha^{-1}), kernel yield (1.56 t ha^{-1}), haulm yield (2.79 t ha^{-1}), biological yield (4.74 t ha^{-1}), harvest index (40.93 %), shelling percentage (79.59 %), seed protein content (24.79 %), seed oil content (46.16 %), seed nitrogen content (3.97 %), seed sulphur content (0.24 %) and seed germination percentage (91.42 %) were observed in S_3 treatment. While the lowest number of pegs plant^{-1} of groundnut (21.53), pods plant^{-1} (14.56), kernel pod^{-1} (1.60), 100 seed weight, pod yield (1.58 t ha^{-1}), kernel yield (1.12 t ha^{-1}), haulm yield (2.48 t ha^{-1}), biological yield (4.06 t ha^{-1}), harvest index (38.73 %), shelling percentage (71.22 %), seed protein content (19.22%), seed oil content (38.24%), seed nitrogen content (3.08 %), seed sulphur content (0.20%) and seed germination percentage (79.17 %) were observed in S_0 treatment.

In case of treatment combination the growth parameters, such as plant height, number of branches plant^{-1}, number of leaves plant^{-1}, dry weight plant^{-1} (g), number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} varied as a result of the combined effect of various nitrogen and sulphur application doses. However, in terms of yield contributing characteristics yield and quality characteristics of groundnut the highest number of pegs on plant^{-1} (33.33), pod number plant^{-1} (27.78), kernel pod^{-1} (2.00), 100 seed weight (65.62 g), pod yield (2.37 t ha^{-1}), kernel yield (1.95 t ha^{-1}), haulm yield (3.21 t ha^{-1}), biological yield (5.58 t ha^{-1}), harvest index (42.47 %), shelling percentage (82.28 %), seed protein content (29.56 %), seed oil content (51.62 %), seed nitrogen content (4.73 %), seed sulphur content (0.29 %) and seed germination percentage (96.33 %) were observed in N_3S_3 treatment combination followed by N_3S_2 treatment combination for yield and N_3S_1 and N_3S_2 treatment combination for quality seed production of groundnut. While the lowest number of pegs on plant^{-1} (17.78), pod number plant^{-1} (11.33), kernel pod^{-1} (1.49), 100 seed weight (35.59 g), pod yield (1.37 t ha^{-1}), kernel yield (0.97 t ha^{-1}), haulm yield (2.22 t ha^{-1}), biological yield (3.59 t ha^{-1}), harvest index (38.16 %), shelling percentage (70.80 %), seed protein content (15.63 %), seed oil content (29.59 %), seed nitrogen content (2.50 %), seed sulphur content (0.15 %), and seed germination percentage (78.00 %) were observed in N_0S_0 treatment combination.

Conclusion

The application of different doses of nitrogen and sulphur resulted in significant differences in groundnut growth, yield, and quality parameters.

- The experimental findings revealed that significant differences for different growth parameters but significantly varied for different yield and quality attributes of groundnut. Among the various nitrogen application doses, N_2 (25 kg Urea ha^{-1}/11.5 kg Nitrogen ha^{-1}) to N_3 (30 kg Urea ha^{-1}/13.8 kg Nitrogen ha^{-1}) treatments outperformed other treatments in terms of yield and quality of groundnut.
- Among the various sulphur application doses, S_2 (300 kg Gypsum ha^{-1} /54 kg Sulphur ha^{-1}) to S_3 (350 kg Gypsum ha^{-1}/63 kg Sulphur ha^{-1}) treatments outperformed other treatments in terms of yield and quality of groundnut.

- N_3 and N_2, combined with S_3 treatment resulted in good groundnut yield and seed qualities. Therefore N_2 to N_3 treatment combination with S_2 to S_3 would be used to quality groundnut seed production without sacrificing yield.

Therefore it may be concluded that both nitrogen and sulphur had beneficial effect on yield and quality seed production of groundnut. Application of nitrogen (25-30 kg Urea ha^{-1}) and sulphur (300-350 kg Gypsum ha^{-1}) along with 5 ton cowdung, 160 kg TSP, 85 kg MoP, and 10 kg Boric acid exhibited the best performance on yield and quality seed production compared to other treatment combination.

Recommendation

Further research in the following areas may be suggested based on the results of the current experiment:

i. A similar study in different agro-ecological zones (AEZ) of Bangladesh is required for regional adaptability;
ii. Other management practices may be included for additional research, and
iii. Other nitrogen and sulphur fertilizer sources and doses could be used for further research to narrow down the specific combination.

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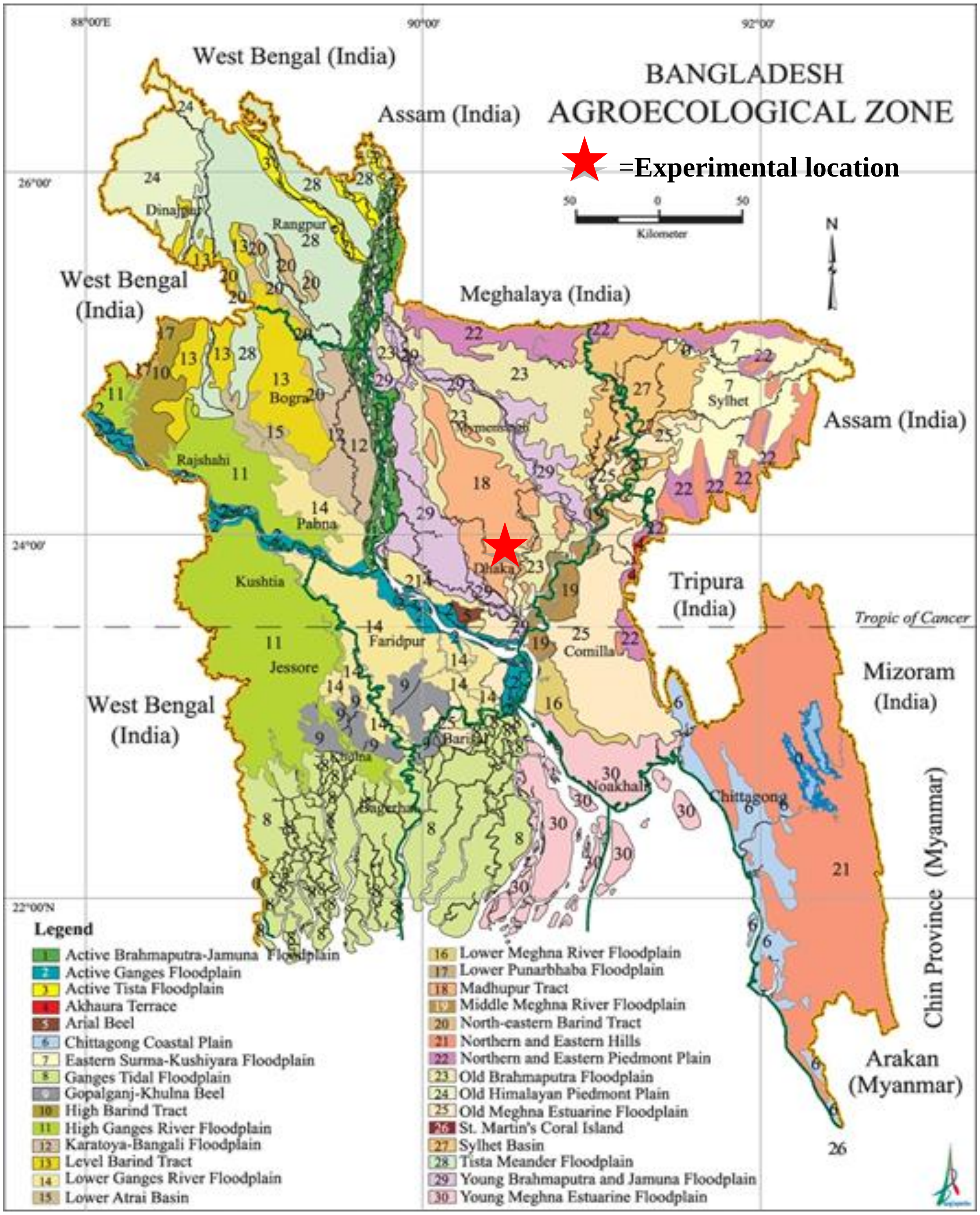
APPENDICES

Appendix I. Map showing the experimental location under study



Appendix II. Soil characteristics of the experimental field

A. Morphological features of the experimental field

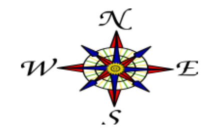
Morphological features	Characteristics
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
Soil series	Tejgaon
Topography	Fairly leveled

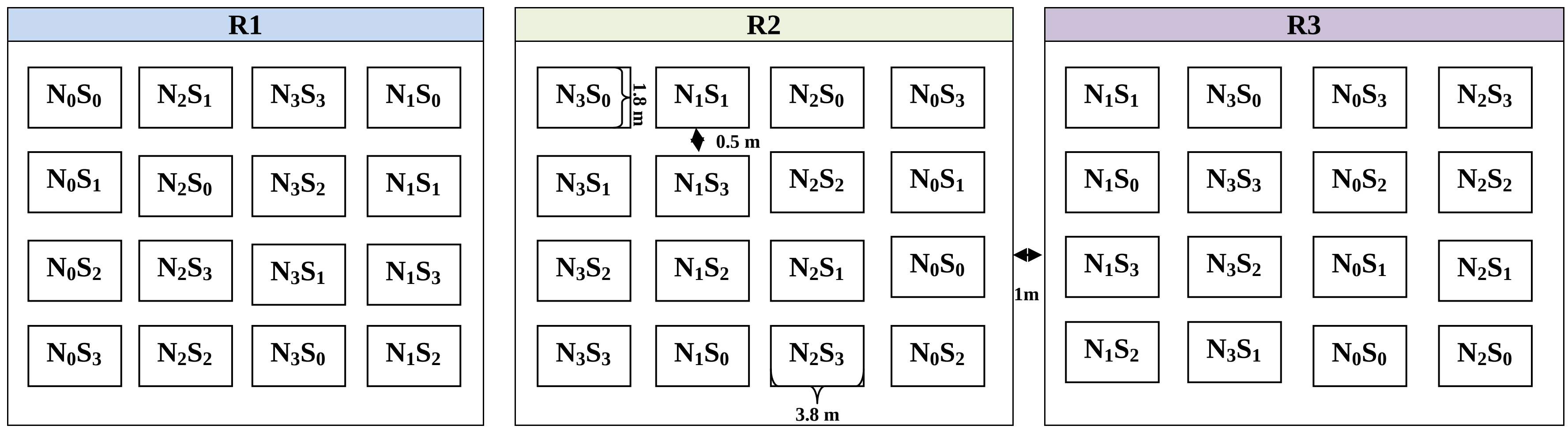
B. The initial physical and chemical characteristics of soil of the experimental site (0- 15 cm depth)

Physical characteristics	
Constituents	**Percent**
Clay	29 %
Sand	26 %
Silt	45 %
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	**Value**
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10
Organic carbon (%)	0.45
Organic matter (%)	0.78
pH	5.6
Total nitrogen (%)	0.03

Sourse: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka.

Appendix III. Layout of the experimental plot





Factor A: Different levels of nitrogen (4) *viz;*
N_0: 0 kg Urea (control) ha^{-1}
N_1: 20 kg Urea ha^{-1} (Recommended)
N_2: 25 kg Urea ha^{-1}
N_3: 30 kg Urea ha^{-1}

Factor B: Different levels of sulphur (4) *viz;*
S_0: 0 kg Gypsum ha^{-1} (control)/ha
S_1: 250 kg Gypsum ha^{-1} (Recommended)
S_2: 300 kg Gypsum ha^{-1}
S_3: 350 kg Gypsum ha^{-1}

The size of unit plot: 3.8 m × 1.8 m.
Row to row distances: 30 cm
Plant to plant distances:15 cm.
The distance between the two plots was 0.5 m, and
The blocks were 1 m apart.

Appendix IV. Monthly meteorological information during the period from February to August, 2020.

Year	**Month**	**Air temperature (^0C)**		**Relative humidity (%)**	**Average rainfall (mm)**
		Maximum	**Minimum**		
2020	February	25.9 ^{0}C	14 ^{0}C	34%	7.7 mm
	March	32.9°C	20.1°C	61%	54 mm
	April	34.1°C	23.6°C	67%	138 mm
	May	33.4°C	24.7°C	76%	269 mm
	June	34°C	27.3°C	76%	134 mm
	July	32.6°C	25.5°C	80%	106 mm
	August	32.4°C	25.7°C	80%	86 mm

Source: Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix V. Mean sum square values of the data for plant height at different days after sowing of groundnut

Source of Variation	DF	Mean Sum square values of plant height at			
		30 DAS	60 DAS	90 DAS	At harvest
Replication	2	0.1458	4.5208	1.1875	3.0625
Nitrogen (N)	3	14.7922**	64.8224**	44.4837**	14.7788**
Error	6	0.8958	1.5208	0.9375	1.0625
Sulphur (S)	3	37.0609**	82.0501**	59.6893**	35.7456**
N×S	9	10.0158**	1.3194*	9.1258**	21.4619**
Error	24	0.7083	2.2708	1.5000	1.3125

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VI. Mean sum square values of the data for number of branches plant^{-1} at different days after sowing of groundnut

Source of Variation	DF	Mean Sum square values of branches at			
		30 DAS	60 DAS	90 DAS	At harvest
Replication	2	0.02250	0.25000	0.18750	0.07562
Nitrogen (N)	3	1.39947**	2.07917**	3.58612**	0.68002*
Error	6	0.00750	0.08333	0.10417	0.07562
Sulphur (S)	3	4.16672**	4.04812**	6.35003**	3.62722**
N×S	9	0.63112**	0.54345**	0.42707**	0.52224**
Error	24	0.01125	0.12500	0.12500	0.05896

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VII. Mean sum square values of the data for number of leaves plant^{-1}at different days after sowing of groundnut

Source of Variation	DF	Mean Sum square values of leaves at			
		30 DAS	60 DAS	90 DAS	At harvest
Replication	2	1.5625	6.250	12.250	4.000
Nitrogen (N)	3	38.7663**	97.175**	152.865**	108.509**
Error	6	0.5625	2.250	4.250	1.333
Sulphur (S)	3	41.1524**	194.480**	120.275**	94.346**
N×S	9	6.1170*	9.540*	4.670*	5.192*
Error	24	0.8125	3.250	6.250	2.000

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VIII. Mean sum square values of the data for dry weight plant^{-1}, number of nodules plant^{-1}, dry weight of nodules plant^{-1} (g) and number of flowers plant^{-1} of groundnut

Source of Variation	DF	Mean Sum square values of			
		Dry weight plant^{-1} (g)	Number of nodules plant^{-1}	Dry weight of nodules plant^{-1} (g)	Number of flowers plant^{-1}
Replication	2	0.771	14.063	0.00016	0.6806
Nitrogen (N)	3	107.107**	946.482**	0.01378**	17.3728**
Error	6	0.521	5.729	0.00009	0.5306
Sulphur (S)	3	21.310**	183.490**	0.00267**	13.0167**
N×S	9	2.373**	22.752*	0.00033*	1.0143*
Error	24	0.583	7.813	0.00011	0.5681

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix IX. Mean sum square values of the data for number of pegs plant^{-1}, pods plant^{-1}, kernel pod^{-1} and 100 seed weight of groundnut

Source of Variation	DF	Mean Sum square values of			
		Pegs plant^{-1} (No.)	Pods plant^{-1} (No.)	Kernel pod^{-1} (No.)	100 seed weight
Replication	2	3.063	1.000	0.00771	6.250
Nitrogen (N)	3	223.766**	184.870**	0.17392**	982.985**
Error	6	2.063	0.500	0.00354	2.083
Sulphur (S)	3	52.471**	88.644**	0.08632**	132.894**
N×S	9	3.233**	4.735**	0.00847**	8.908*
Error	24	0.979	0.625	0.00458	3.125

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix X. Mean sum square values of the data for pod yield, kernel yield, haulm yield, biological yield, harvest index and shelling % of groundnut

Source of Variation	DF	Mean Sum square values of					
		Pod yield	Kernel yield	Haulm yield	Biological yield	Harvest index	Shelling %
Replication	2	0.01562	0.00188	0.01000	0.01563	2.2500	3.938
Nitrogen (N)	3	1.16737 **	0.92727 **	1.44373 **	5.19332 **	15.3290 **	68.719 **
Error	6	0.00562	0.00354	0.00333	0.00896	0.9167	2.438
Sulphur (S)	3	0.30112 **	0.40612 **	0.20752 **	1.00712 **	9.7481 **	157.545 **
N×S	9	0.03447 **	0.03454 *	0.03071 **	0.12472 **	0.8700 **	11.800 **
Error	24	0.00812	0.00312	0.00500	0.01063	1.2500	2.813

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix XI. Mean sum square values of the data for seed protein content, oil content, seed nitrogen content, seed sulphur content and seed germination percentage of groundnut

Source of Variation	DF	Mean Sum square values of				
		Seed protein content (%)	Seed oil content (%)	Seed nitrogen content %	Seed sulphur content %	Seed germination (%)
Replication	2	3.062	6.250	0.05063	0.00040	0.750
Nitrogen (N)	3	155.643 **	519.455 **	3.98902 **	0.02452 **	236.15**
Error	6	3.062	6.250	0.01729	0.00015	1.417
Sulphur (S)	3	65.834**	139.030 **	1.68592 **	0.00287 **	306.56**
N×S	9	2.450*	23.419*	0.06288*	0.00004*	22.94**
Error	24	1.396	4.750	0.02563	0.00021	1.250

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability