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Assessment of Nitrogen and Sulphur Nutrition to Optimize the Yield and Quality of Groundnut (*Arachis hypogaea* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. Author JVS did ideal conception and implementation of the research. Author AO did conduct of experiment, data collection, analysis of the results and writing of the manuscript. Authors SKV, NM and AF participated in reviewing and editing of manuscript. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during February 2023 to June 2023 at Kerala Agricultural University, College of Agriculture, Padannakkad, Kasargod with the objective of formulating a nutrient schedule for groundnut, consisting different sources of nutrients (especially nitrogen and

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sulphur), time and method of application. The experiment was laid out in randomized block design with 9 treatment combinations of 2 factors, viz., Nutrient Schedule (S) and Foliar Nutrition (F), with 3 treatments each, viz., S1: nitrogen (10 kg ha-1) and sulphur (20 kg ha-1) as per package of practices as basal, S2: nitrogen and sulphur each @ 10 kg ha-1 in 2 equal splits (one as basal and the other at 20 days after sowing), S3: control (without nitrogen and sulphur), F1: foliar application of urea and potassium sulphate @ 1% each at 10 and 30 days after sowing, F2: foliar application of nano urea @ 3 ml 1-1 and nano sulphur @ 1 ml 1-1 each at 10 and 30 days after sowing, F3: control (without foliar application). The main effects of the treatments were significant with S1 recording taller plants at 20 (8.16 cm), 40 (18.05 cm) and 60 (30.34 cm) days after sowing and S2 at 80 days after sowing (37.61 cm). Foliar nutrition was found effective with application of nano fertilisers (F2), recording 11.17%, 27.02% and 18.75% taller plants than control at 40, 60 and 80 days respectively after sowing. The treatment combination S1F2 recorded the tallest plants at different growth stages with heights 18.61 cm, 34.50 cm and 41.50 cm respectively at 40, 60 and 80 days after sowing. The leaf area of groundnut varied significantly with treatments and their combinations. Application of nitrogen and sulphur @ 10 kg ha-1 each in 2 splits (S2) was superior to other treatments in recording higher leaf areas at 40, 60 and 80 days after sowing with respective values of 747.16 cm2, 1435.60 cm2 and 1216.20 cm2. Foliar nutrition with conventional urea and potassium sulphate (F1) recorded significantly higher leaf area at 40 (734.87 cm2) and 60 (1382.70 cm2) days after sowing and it was at par with foliar application of nano fertilisers (F2) at 40 days after sowing (716.70 cm2). Application of nitrogen and sulphur in 2 splits and foliar spray of nano urea and nano sulphur (S2F2) recorded maximum leaf area at 60 (1543.83 cm2) and 80 (1341.51 cm2) days after sowing. The plants which received nitrogen and sulphur in two equal splits (S2) and foliar application of nano urea and nano sulphur (F2) or their combination (S2F2) were superior in terms of kernel yield of groundnut with values 1925.87 kg ha-1, 1801.70 kg ha-1 and 2109.80 kg ha-1 respectively. The highest oil content was obtained with the treatment S2 (48.01 %) and it was on par with S1 (47.73 %). The effect of foliar nutrition was also significant and the treatments F2 and F1 were on par and they recorded 48.04 % and 47.81 %, respectively. Integrated application of nitrogen and sulphur each @10 kg ha-1as basal and foliar spray of nano fertilisers (S1F2) recorded the highest (49.30 %) oil content and it was on par with S2F1 (49.10 %) and S2F2 (48.4 %).

Keywords: Groundnut; nitrogen; sulphur; foliar application; nano urea; nano sulphur.

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.), which ranks 6th among the oilseed crops and 13th among the food crops of the world, provides high quality edible oil (48–50%), easily digestible protein (26–28%) and nearly half of the 13 essential vitamins and 7 of the 20 essential minerals and high-quality fodder for livestock [1].

Globally, groundnut covers 327 lakh hectares with the production of 539 lakh tonnes with the productivity of 1648 kg per hectare [2]. With annual all-season coverage of 54.2 lakh hectares, globally, India ranks first in groundnut area under cultivation and is the second largest producer in the world with 101 lakh tonnes with productivity of 1863 kg per hectare in 2021-22 [3].

Sulphur is very essential for oilseed crops along with nitrogen for protein, enzyme and oil syntheses, carbohydrate as well as protein metabolism. The shortage in sulphur supply to crops reduces the nitrogen use efficiency of crops. Consequently, the poor efficiency of nitrogen utilization caused by insufficient sulphur may increase nitrogen losses from cultivated soils [4]. Different mode of fertilization through split application and foliar nutrition can be suitably adapted to enhance N and S uptake by groundnut.

Nano fertilizers offer unique qualities that promote plant performance by means of higher absorption and translocation of nutrients, considerable rise in leaf surface area and greater photosynthesis. When conventional fertilizer is substituted with nano fertilizer, nutrients are released in a steady and controlled manner into the soil, preventing eutrophication and water contamination [5].

Keeping these points, the present investigation was carried out with an objective to formulate an effective nitrogen – sulphur schedule to groundnut and to study the effect of foliar applied nano-nitrogen and nano-sulphur ferilisers in groundnut. The materials used, methodologies followed, results obtained and the future line of work are presented hereunder.

2. MATERIALS AND METHODS

The field experiment was carried out at Kerala Agricultural University, College of Agriculture, Padannakkad, Kasaragod, during the summer season of 2023 (January to June, 2023). The field was located at12° 20' 30" N latitude and 75° 04' 15" E longitude at an altitude of 20 m above the mean sea level. This area enjoys a typical warm humid tropical climate. The field was left fallow prior to the layout of the experiment.

The soil of the experimental site was sandy, which belongs to the taxonomical order entisol, neutral in reaction, low in organic carbon (0.35 %), low in available nitrogen (149.5 kg ha^{-1}), high in available phosphorus (51.4 kg ha^{-1}), medium in available potsssium (152.1 kg ha^{-1}) and deficient in available sulphur (3.3 kg ha^{-1}). The experiment was laid out in factorial randomized block design of 2 factors, *viz*., nutrient schedule and foliar nutrition with 3 levels each. Nutrient schedule includes, S_1: nitrogen (10 kg ha^{-1}) and sulphur (20 kg ha^{-1}) as per package of practices (PoP) as basal, S_2: nitrogen and sulphur each @ 10 kg ha^{-1} in 2 equal splits (one as basal and the other at 20 days after sowing), S_3: control (without nitrogen and sulphur). Foliar nutrition includes, F_1: foliar application of urea and potassium sulphate @ 1% each at 10 and 30 days after sowing, F_2: foliar application of nano urea @ 3 ml 1^{-1} and nano sulphur @ 1 ml 1^{-1} each at 10 and 30 days after sowing, F_3: control (without foliar application).

Treatments include:

S_1F_1: N and S as per Package of Practices (PoP)* as basal and foliar spray of urea and potassium sulphate @ 1% each at 10 and 30 DAS

S_1F_2: PoP as basal and foliar spray of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} at 10 and 30 DAS

$S_1F_{3:}$ PoP as basal without foliar nutrition

S_2F_1: N and S @ 10 kg ha^{-1} each in 2 splits (basal and 20 DAS) and foliar spray of urea and potassium sulphate @ 1% each at 10 and 30 DAS

S_2F_2: N and S @ 10 kg ha^{-1} each in 2 splits (basal and 20 DAS) and foliar spray of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} at 10 and 30 DAS

S_2F_3: N and S @ 10 kg ha^{-1} each in 2 splits (basal and 20 DAS) without foliar nutrition

S_3F_1: PoP without N and S and foliar spray of urea and potassium sulphate @ 1% each at 10 and 30 DAS

S_3F_2: PoP without N and S and foliar spray of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} at 10 and 30 DAS

S_3F_3: PoP without N, S and foliar spray

*Recommended dose of fertilizer for groundnut according to Package of Practices recommendations is 10:75:75:20 kg N, P, K, S ha^{-1}.

A fertilizer dose of 75 kg ha^{-1} of K_2O and P_2O_5 were applied to all the plots as basal dose. For foliar application, nano fertilizers including nano urea and nano S was used. The liquid formulation of nano nitrogen contained 40000 ppm of N, whereas the nano S liquid formulation contains 50000 ppm of S. The variety of groundnut used was CO-7. The plot size was 3.75 m x 3.75 m. Observations on growth parameters were recorded using six randomly selected plants from each net plot.

3. RESULTS AND DISCUSSION

3.1 Plant Height (cm)

Plant height varied significantly with the nutrient schedule at all growth stages (Table 1). Basal application of fertilisers as per PoP (S_1) recorded the highest plant height at 20 DAS (8.16 cm), 40 DAS (18.05 cm) and 60 DAS (30.34 cm) and it was on par with S_2 ($N_{10}S_{10}$ as 2 splits) at 20 DAS (7.63 cm) and 80 DAS (37.61 cm). At 80 DAS, highest plant height was recorded with S_2 ($N_{10}S_{10}$ as 2 splits) and it was on par with S_1 (application of fertilisers as per POP as basal). Lowest plant height was observed with the treatment, S_3 (POP without N and S). This might be due to increased availability of N and S in the initial stage which have direct influence on plant photosynthetic process and meristematic activity, thus improving plant height. Similar results of comparable plant heights in basal as well as split application of N fertilizer was reported by Głowacka *et al* [6]. The effect of foliar nutrition on plant height was also significant at all growth stages except at 20 DAS. The highest value for plant height was observed with the application of nano urea (3 ml l^{-1}) and nano S (1 ml l^{-1}) at 40 DAS (16.72 cm), 60 DAS (31.31 cm) and 80 DAS (38 cm) and it was on par with the foliar spray of urea (1%) and SOP (1%) at 40 DAS (16.29 cm) and 80 DAS (36.8 cm).

The effect of interaction between nutrient schedule and foliar nutrition was significant with respect to plant height at all growth stages except at 20 DAS. Integrated application of PoP as basal + foliar spray of nano urea 3 ml l^{-1} and nano S 1 ml l^{-1} (S_1F_2) recorded the highest plant height (18.61 cm) at 40 DAS and it was on par with S_1F_3 (18.06 cm), S_2F_1 (18.16 cm) and S_2F_2 (18.39 cm). At 60 DAS and 80 DAS the highest plant height (34.5 cm & 41.5 cm) was recorded with PoP as basal + foliar spray of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} (S_1F_2) and it was on par with S_2F_1 (40.46 cm) and S_2F_2 (40.43 cm) at 80 DAS. Benzon *et al.* (2015), discussed the possible synergistic effect of nano fertilizers on conventional fertilizers, affecting root uptake to foliage penetration and movement of nutrients within the plant, leading to better intake of nutrients and higher plant height.

3.2 Leaf Area Per Plant (cm^2)

Nutrient schedule imparted significant variation in leaf area of groundnut (Fig. 1) and the treatment S_1 (application of fertilisers as per PoP as basal) recorded the highest value of 165.4 cm^2 at 20 DAS. During all other growth stages, the treatment S_2 was significantly superior (747.16 cm^2, 1435.6 cm^2 and 1216.2 cm^2 respectively at 40, 60 and 80 DAS) to all other treatments and it was on par with S_1 at 40 DAS (710.03 cm^2).

Findings of Ahmad *et al*. [7] show that providing sufficient N and S in split dosages during the growth phases result in greater utilization of carbohydrates to create more protoplasm and bigger cells which may result in an increase in leaf area. The effect of foliar nutrition on leaf area per plant (Fig. 2) was also significant at 40 and 60 DAS. Foliar spray of urea and SOP @ 1% each at 10 and 40 DAS (S_1) recorded the highest value of 734.87 cm^2 at 40 DAS and 1382.7 cm^2 at 60 DAS. It was on par with S_2 at 40 DAS (716.7 cm^2). Interaction effect was also significant at all growth stages except at 20 DAS (Fig. 3).

Table 1. Plant height (cm) of groundnut as influenced by nutrient schedule and foliar nutrition

Treatment	20 DAS	40 DAS	60 DAS	80 DAS
Nutrient Schedule (S)				
S_1 – POP* as basal	8.16	18.05	30.34	36.91
S_2 – N & S 10 kg each in 2 splits	7.63	16.67	28.28	37.61
S_3 – POP without N and S as basal	6.58	13.33	25.26	32.29
SEm (±)	0.266	0.287	0.538	0.536
CD (P=0.05)	0.797	0.859	1.612	1.608
Foliar Nutrition (F)				
F_1 - Urea + SOP	7.38	16.29	27.82	36.80
F_2 - Nano urea + Nano S	7.71	16.72	31.31	38.00
F_3 - Control	7.28	15.04	24.65	32.00
SEm (±)	0.266	0.287	0.538	0.536
CD (P=0.05)	NS	0.859	1.612	1.608
Interaction (S x F)				
S_1F_1	8.36	17.46	30.10	36.03
S_1F_2	8.23	18.61	34.50	41.50
S_1F_3	7.86	18.06	26.40	33.20
S_2F_1	7.10	18.16	29.90	40.46
S_2F_2	8.26	18.39	31.57	40.43
S_2F_3	7.53	13.46	23.30	31.90
S_3F_1	6.60	13.33	23.40	33.90
S_3F_2	6.63	13.76	27.80	32.06
S_3F_3	6.43	13.20	23.10	30.90
SEm (±)	0.461	0.496	0.931	0.929
CD (P=0.05)	NS	1.488	2.792	2.785

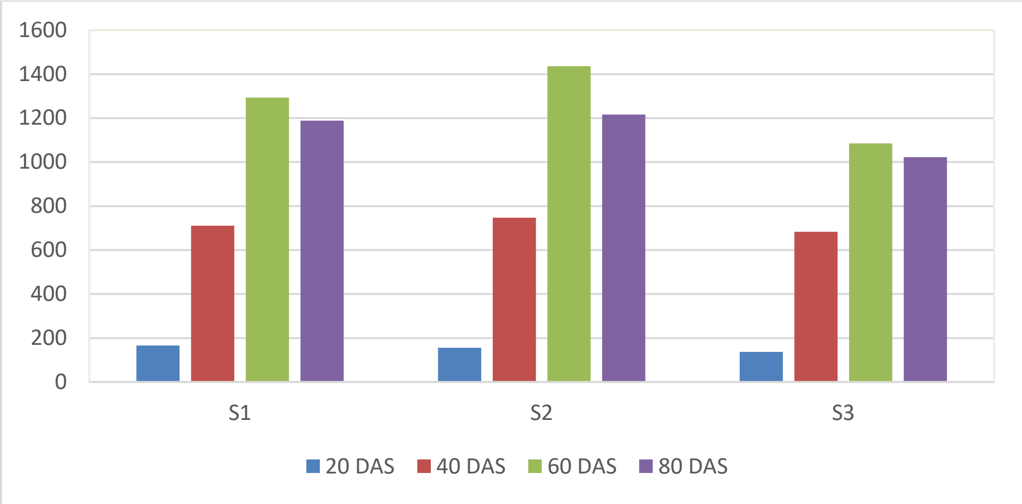

Fig. 1. Effect of nutrient schedule on leaf area per plant (cm^2) of groundnut

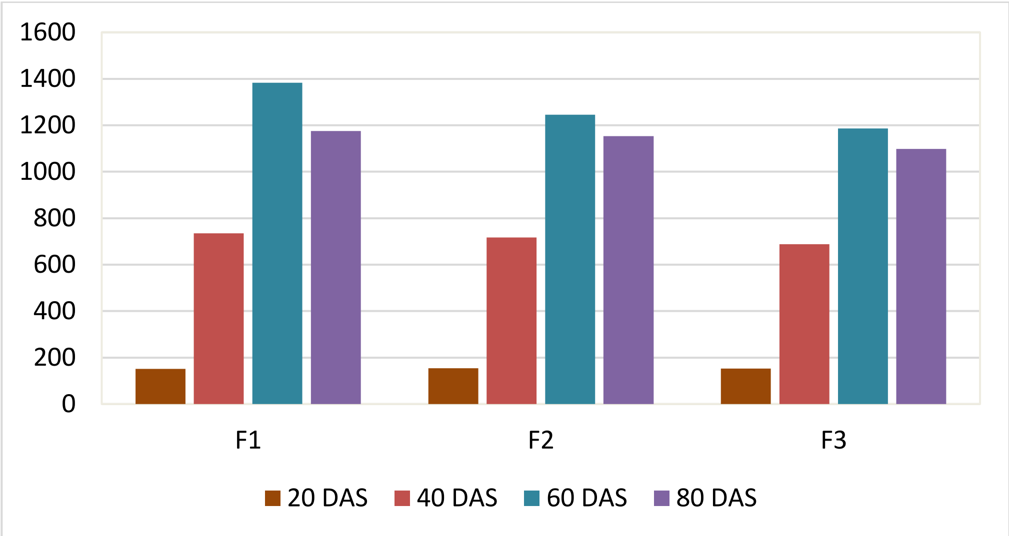

Fig. 2. Effect of foliar nutrition on leaf area (cm^2) of groundnut

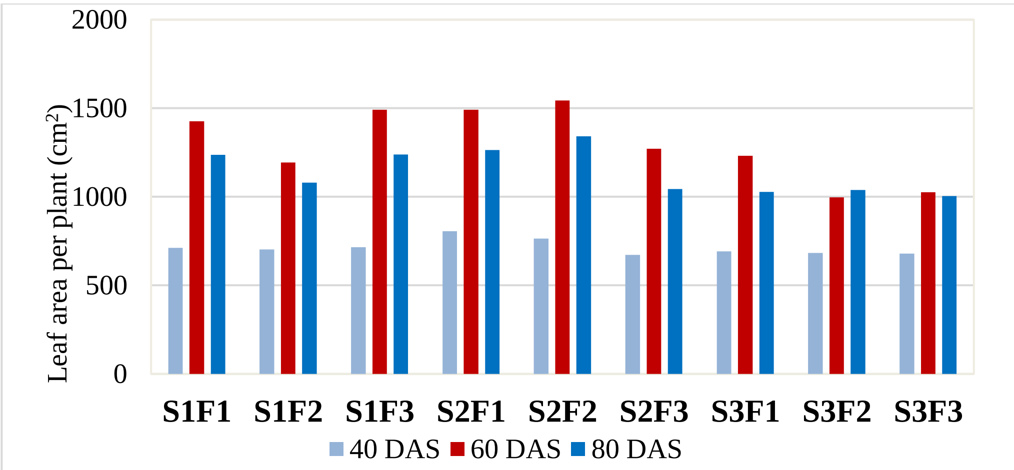

Fig. 3. Effect of nutrient schedule and foliar nutrition on leaf area per plant (cm^2) of groundnut

Integrated application of N and S @ 10 kg ha^{-1} each in 2 splits (basal and 20 DAS), and foliar application of 1 % each urea and SOP at 10 and 30 DAS (S_2F_1) recorded the highest leaf area per plant (805.27 cm^2) at 40 DAS. At 60 DAS, the highest leaf area of 1543.83 cm^2 was recorded with integrated application of N and S @ 10 kg ha^{-1} each as 2 splits (basal and 20 DAS) and foliar spray of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} (S_2F_2) and it was on par with S_2F_1 (1491.27 cm^2) and S_1F_1 (1425.67 cm^2). The treatment combination, S_2F_2 recorded the highest leaf area (1341.51 cm^2) at 80 DAS also and it was on par with S_2F_1 (1263.6 cm^2), S_1F_3 (1248.23 cm^2) and S_1F_1 (1236.47 cm^2). Foliar feeding of important nutrients, particularly N, resulted in the production and maintenance of greater chlorophyll and photosynthetic area in the form of increased leaf area [8].

3.3 Dry Matter Per Plant

Dry matter production varied significantly among the treatments at all stages of growth except at 20 DAS (Table 2). Application of N and S @ 10 kg ha^{-1} each (S_2) as 2 equal splits (basal and 20 DAS) recorded the highest dry matter per plant at 40 DAS (10.0 g) and 60 DAS (16.67 g) and it was on par with S_1 (PoP as basal) at 40 DAS (9.69 g). The treatments, S_1 (23.89 g) and S_2 (23.67 g) were on par at 80 DAS. Findings of Ahmad *et al*. [7] revealed that split application of N and S enhances the nutrient availability, results in higher leaf expansion, subsequent capture and efficient usage of solar radiation, resulting in greater dry matter deposition in leaves and shoots. The effect of foliar nutrition on dry matter production was significant at 40 and 80 DAS with F_1 and F_2 recording the highest values respectively as 10.04 g and 24.22 g. At 80 DAS, F_2 was on par with F_1 (23.67 g). The interaction effect was also significant at 40 DAS with S_2F_1 recording the highest dry matter of 10.82 g per plant and it was on par with S_1F_2 (10.55 g). The increase in dry matter output could be attributed to the crop's rapid uptake and assimilation of nutrients which are supplied through foliar application [8].

Table 2. Drymatter production per plant of groundnut as influenced by nutrient schedule and foliar nutrition

Treatment	20 DAS	40 DAS	60 DAS	80 DAS
Nutrient Schedule (S)				
S_1 – POP* as basal	0.97	9.69	15.56	23.89
S_2 – N & S 10 kg each in 2 splits	1.03	10.00	16.67	23.67
S_3 – POP without N and S as basal	0.99	9.13	15.33	21.00
SEm (±)	0.077	0.145	0.285	0.545
CD (P=0.05)	NS	0.436	0.885	1.635
Foliar Nutrition (F)				
F_1 - Urea + SOP	1.10	10.04	16.22	23.67
F_2 - Nano urea + Nano S	0.92	9.60	15.89	24.22
F_3 - Control	0.97	9.19	15.44	20.67
SEm (±)	0.077	0.145	0.285	0.545
CD (P=0.05)	NS	0.436	NS	1.635
Interaction (S x F)				
S_1F_1	1.05	9.52	16.00	24.60
S_1F_2	0.85	10.55	15.33	25.00
S_1F_3	1.02	8.99	15.33	22.00
S_2F_1	1.28	10.82	16.66	25.00
S_2F_2	0.89	9.99	17.00	25.66
S_2F_3	0.92	9.19	16.33	20.33
S_3F_1	0.97	9.77	16.00	21.00
S_3F_2	1.02	9.05	15.33	22.00
S_3F_3	0.98	8.56	14.67	19.66
SEm (±)	0.134	0.252	0.494	0.944
CD (P=0.05)	NS	0.755	NS	NS

3.4 Yield Attributes

The hundred kernel weight of groundnut varied significantly with nutrient schedule and the treatment S_2 recorded the highest value of 43.17 g and it was on par with S_1 (42.46) (Table 3). Hundred kernel weight did not vary with foliar nutrition and SxF interaction. Number of pods per plant differed significantly with varying nutrient schedules and foliar nutrition. The treatments.

S_2 (application of N and S @ 10 kg ha^{-1} each in 2 splits) and F_2 (Foliar application of nano urea @ 3 ml l^{-1} and nano S @ ml l^{-1}) recorded the highest values of 21.00 and 20.56, respectively. The interaction effect was not significant. Nutrient schedule and foliar nutrition and their interaction did not have significant effect on days to 50% flowering and number of seeds per pod. As Ahmad *et al*. [7] reported, supplying balanced doses of N and S to crop is possible through split application of nutrients, which facilitates increased availability of photosynthates to the reproductive parts and increased development of reproductive structures. An enhanced supply of photosynthates to pods would also let seeds to grow to their maximum capacity, resulting in an evident rise in hundred kernel weight. Thirunavukkarasu [9] reported that application of 30 kg ha-1 of nano S recorded highest number of pods per plant in groundnut compared to conventional S application.

3.5 Kernel and Haulm Yield

The kernel yield varied significantly with nutrient schedule (Fig. 4), foliar nutrition (Fig. 5) and their interaction (Fig. 6). The treatment S_2, *viz*., the application of 10 kg ha^{-1} each of N and S in 2 equal splits (basal and 20 DAS), was significantly superior to all other treatments and it recorded the highest kernel yield of 1925.87 kg ha^{-1}. Ahmad *et al*. [7] reported an enhancement in growth and yield characteristics with split application of S and N in brassica. Zainab *et al.* [10] obtained the highest seed yield in soyabean by applying 60 kg ha^{-1} of N in two portions; one quarter before sowing, and the rest at the start of seed-filling. Liu *et al*. [11] revealed that N supplied through the split application met crop requirements, facilitating dry matter transport from vegetative organs to grain and pod during yield formation and thereby improving yield. Although basal N is required for crop vegetative growth in the early stages, timely topdressing in the middle or later stages is critical for achieving better kernel yields. The study conducted by Balasubramanian [12] revealed that split N treatment coincided with peg formation resulted in increased pod output, which supports the findings of this study.

Significantly highest kernel yield was observed with F_2 (foliar application of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} at 10 and 30 DAS) recording a value of 1801.70 kg ha^{-1}. Interaction effect was significant and the treatment S_2 in combination with F_1 and F_2 (S_2F_1 and S_2F_2) were on par with respect to the kernel yield, recording the values of 2035.5 kg ha^{-1} and 2109.50 kg ha^{-1}, respectively. Foliar application of nano urea fertilizer along with 75% of recommended dose of N supplied higher N to the plant throughout the growth stages resulting in increased interception of photosynthetically active radiation and greater photosynthesis in rice. Moreover, nano urea application resulted in enhanced starch translocation from leaves and straw to grain which produced higher grain yield. Sahu *et al*., [13]. These result findings were in close agreement with the findings of Kumar *et al*. [14]. Thirunavukkarasu [15] reported highest kernel yield in groundnut with the application of 30 kg ha^{-1} of nano S compared to conventional S and it might be due to the higher S uptake, improved availability of critical nutrients in soil possible through the use of nano S fertilizer.

Highest haulm yield of 4492.04 kg ha^{-1} was obtained with the nutrient schedule, S_2 (application of N & S @ 10 kg ha^{-1} each in 2 splits as basal and at 20 DAS). A considerable increase in haulm yield owing to split N administration could be attributed to its direct influence on dry matter accumulation and plant stand [16]. Similar results of higher haulm yield in groundnut by split application of N is recorded by Pareek and Poonia [17]. Foliar application of 1 % each urea and SOP at 10 and 30 DAS (F_1) recorded the highest haulm yield (4299.14 kg ha^{-1}) and it was on par with the treatment F_2, *viz*., application of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} at 10 and 30 DAS (4274.70 kg ha^{-1}). According to Lahari *et al*. [18] the increase in straw production with the foliar spray of nano N and nano zinc fertilizers could be attributed to the fact that nano fertilizers are rapidly absorbed by plant body and easily translocated at a higher rate, which helps in faster photosynthesis and more dry matter formation resulting in increased straw yield. Integrated application of N and S @ 10 kg ha^{-1} each in 2 splits (basal and 20 DAS) and foliar application of nano urea @ 3 ml l^{-1} and nano S @ 1 ml l^{-1} at 10 and 30 DAS (S_2F_2)

recorded the highest haulm yield (4722.67 kg ha^{-1}) and it was comparable with S_2F_1 (4659.43 kg ha^{-1}). Study conducted by Mehta and Bharat [19] shows that application of NPK as per recommended dose and 3 sprays of nano NPK at 20, 35 and 45 DAS @ 3 ml l^{-1} and 2 Nano K sprays at grain development stage at 110 and 125 DAS @ 4 ml l^{-1} recorded highest straw yield in wheat compared to recommended dose of fertilisers as control. It shows the advantages of nano-fertilizers over traditional fertilizers for improved nutrient absorption and increased photosynthesis which result in optimal plant growth and straw yield.

Table 3. Days to 50 per cent flowering, hundred kernel weight (g), number of pods per plant and number of seeds per pod of groundnut as influenced by nutrient schedule and foliar nutrition

Treatment	Days to 50 per cent flowering	100 kernels weight (g)	No. of pods per plant	No. of seeds per pod
Nutrient Schedule (S)				
S_1 – POP* as basal	30.67	42.46	18.22	1.77
S_2 – N & S 10 kg each in 2 splits	30.78	43.17	21.00	1.93
S_3 – POP without N and S as basal	31.44	40.64	18.56	1.71
SEm (±)	0.914	0.459	0.285	0.075
CD (P=0.05)	NS	1.377	0.855	NS
Foliar Nutrition (F)				
F_1 - Urea + SOP	30.44	42.36	19.22	1.82
F_2 - Nano urea + Nano S	31.56	42.53	20.56	1.85
F_3 - Control	30.89	41.38	18.00	1.77
SEm (±)	0.914	0.459	0.285	0.075
CD (P=0.05)	NS	NS	0.855	NS
Interaction (S x F)				
S_1F_1	30.30	43.60	18.30	1.75
S_1F_2	32.00	42.50	19.30	1.86
S_1F_3	29.60	41.20	17.00	1.69
S_2F_1	31.30	43.40	21.60	2.11
S_2F_2	30.60	43.50	22.30	1.85
S_2F_3	30.30	42.60	19.00	1.83
S_3F_1	29.60	39.90	17.60	1.61
S_3F_2	32.00	41.10	20.00	1.81
S_3F_3	32.60	40.40	18.00	1.69
SEm (±)	0.795	1.584	0.494	0.130
CD (P=0.05)	NS	NS	NS	NS

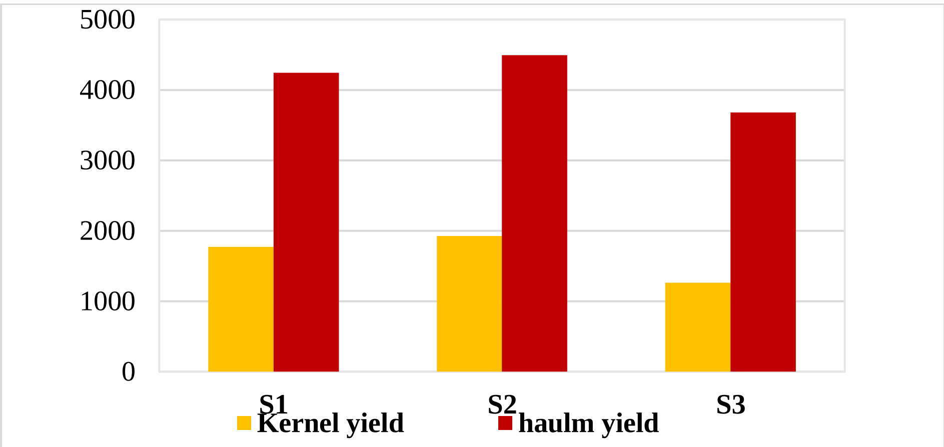

Fig. 4. Effect of nutrient schedule on kernel yield and haulm yield (kg ha^{-1}) of groundnut

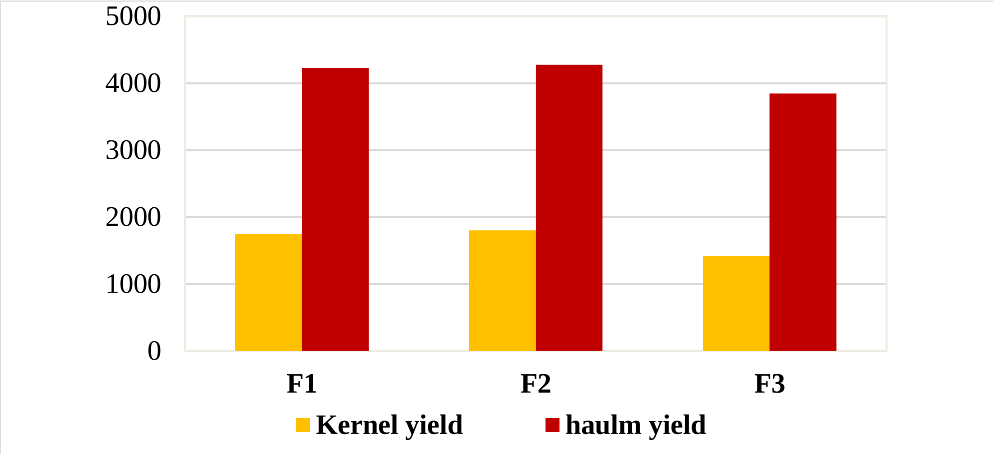

Fig. 5. Effect of foliar nutrition on kernel yield and haulm yield (kg ha^{-1}) of groundnut

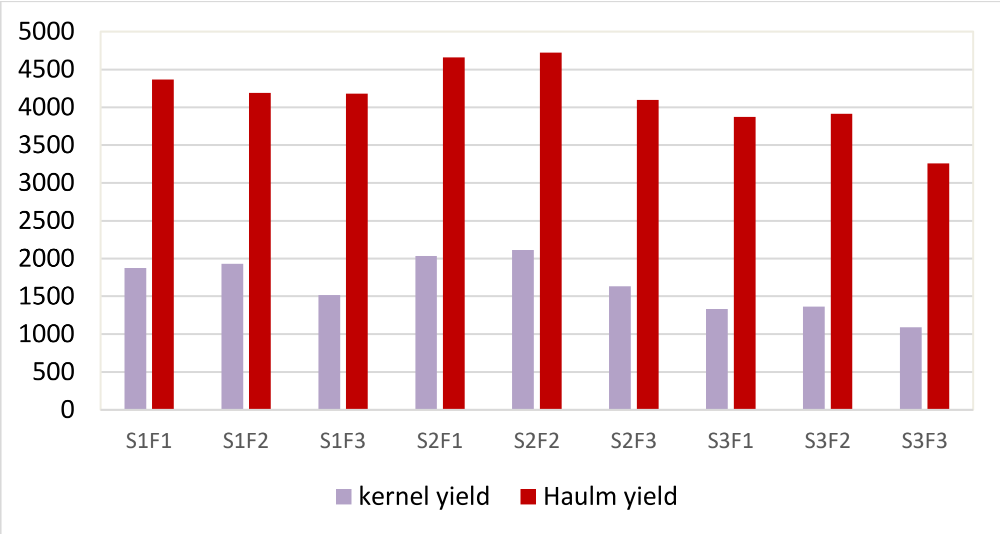

Fig. 6. Effect of nutrient schedule and foliar nutrition on kernel and haulm yield (kg ha^{-1}) of groundnut

3.6 Quality Parameters

The protein, oil content and oil yield were varied significantly with nutrient schedule, foliar nutrition and their interaction (Table 4). Basal application of N and S as per POP (S_1) recorded the highest protein content (21.45 %) and it was on par with the treatment S_2 (application of N and S @ 10 kg ha^{-1} each in 2 splits), with a mean protein content of 20.98 %. Foliar application of nano urea (3 ml l^{-1}) and nano S (1 ml l^{-1}) resulted in significantly highest protein content of 21.89%. Combined application of N and S in 2 splits and foliar spray of nano fertilisers (S_2F_2) recorded the highest protein content (23.26%) and it was on par with S_1F_2 (22.16%). Głowacka *et al.* (2023) revealed that the crude protein level may have increased as a result of the split application of N and S, which boosted the availability of nutrients during the pod growth stage. Thirunavukkarasu (2014) documented that application of nano S increases availability of N and S in groundnut, as S is a component of several amino acids found in protein, and it also participates in various biochemical events that result in increased protein content. Highest oil content (48.01 %) was obtained with the treatment S_2 (N and S @ 10 kg each in 2 splits) and it was statistically comparable (47.73 %) to S_1 (N & S as per POP as basal). The effect of foliar nutrition was also significant and the treatments, F_2 (foliar application of nano urea and nano S) and F_1 (foliar spray of urea and SOP) were on par with respect to the oil content, recording the values of 48.04 % and 47.81 %, respectively. Integrated application of N and S as per POP as basal

Table 4. Crude protein (%), oil content (%) and oil yield (kg ha-1) of groundnut as influenced by nutrient schedule and foliar nutrition

Treatment	Crude protein (%)	Oil content (%)	Oil yield (kg ha^{-1})
Nutrient Schedule (S)			
S_1 – POP* as basal	21.45	47.73	848.17
S_2 – N & S 10 kg each in 2 splits	20.98	48.01	926.73
S_3 – POP without N and S as basal	20.11	45.64	673.31
SEm (±)	0.339	0.276	11.410
CD (P=0.05)	1.017	0.828	34.206
Foliar Nutrition (F)			
F_1 - Urea + SOP	20.49	47.81	867.77
F_2 - Nano urea + Nano S	21.89	48.00	895.18
F_3 - Control	20.16	45.53	685.27
SEm (±)	0.339	0.276	11.410
CD (P=0.05)	1.017	0.828	34.206
Interaction (S x F)			
S_1F_1	21.19	47.30	884.80
S_1F_2	22.16	49.30	952.30
S_1F_3	20.90	46.60	707.40
S_2F_1	19.65	49.10	1000.10
S_2F_2	23.26	48.40	1020.00
S_2F_3	20.03	46.50	759.50
S_3F_1	20.55	47.00	718.50
S_3F_2	20.24	46.50	712.60
S_3F_3	19.56	43.40	588.80
SEm (±)	0.588	0.480	19.760
CD (P=0.05)	1.762	1.430	59.250

and foliar spray of nano fertilisers (S_1F_2) recorded the highest (49.3 %) oil content and it was on par with S_2F_1 and S_2F_2. Higher availability of essential nutrients including plant available S in pod formation stage assisted by nano S application might have affected synthesis of essential metabolites for higher oil content, increased production of glycosides which on hydrolysis produced higher oil. These results are in line with the findings of Thirunavukkarasu [15].

Oil yield differed significantly with treatments and their interaction. An oil yield of 926.73 kg ha^{-1} was recorded with the treatment, S_2 (10 kg N & S each in 2 splits). While, foliar application of nano urea (3 ml l^{-1}) and nano S (1 ml l^{-1}) recorded the highest oil yield of (895.18 kg ha^{-1}) and it was on par (867.77 kg ha^{-1}) with urea (1%) and SOP (1%). Combined application of N and S @ 10 kg ha^{-1} each in 2 splits (basal and 20 DAS) and foliar spray of nano urea @ 3 ml l^{-1} & nano S @ 1 ml l^{-1} (S_2F_2) recorded the highest oil yield of 1020 kg ha^{-1} and it was on par with S_2F_1 (1000 kg ha^{-1}) [20]. Since oil yield is a function of kernel oil content and kernel yield, the treatment which recorded highest oil content and kernel yield also recorded highest oil yield (Cheema *et al*., 2010). Pareek *et al*. (2020) also witnessed an increase in oil yield as a result of higher kernel yield, enhanced crude protein content in kernel due to split N application in groundnut [21,22].

4. CONCLUSION

The study revealed that there was a significant variation in growth, yield attributes, yield and quality parameters of groundnut due to split and foliar application of nutrients. Hence Application of N and S each @ 10 kg ha^{-1} in 2 equal splits (basal and 20 DAS) along with foliar spray of nano urea (3 ml 1^{-1}) and nano S (1 ml 1^{-1}) at 10 and 30 DAS was found to be the best nitrogen sulphur schedule for groundnut.

FUTURE LINE OF WORK

The experiment can be repeated under different seasons, locations, etc. for confirmatory results. Based on the results of the experiment, more split doses, different sources including nano fertilisers and various methods of application of N and S fertilisers can be tested.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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