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EVALUATION OF SULPHUR SOURCES ON YIELD, HARVEST INDEX, AGRONOMIC EFFICIENCY, AND POST-HARVEST SOIL PROPERTIES OF GROUNDNUT UNDER ODISHA CONDITIONS

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ABSTRACT

A field experiment entitled "Evaluation of Sulphur Sources in Groundnut in the Mid-Central Table Land Zone of Odisha" was conducted during the kharif season of 2021 at the Regional Research and Technology Transfer Station (OUAT), Mahisapat, Dhenkanal district, to assess the effect of different sulphur sources on yield, nutrient uptake, and soil fertility. The experiment, laid out in a randomized block design with three replications and seven treatments (1) control, (2) STD (NPK) + S_0, (3) STD (NPK) + S_{40} (Elemental Sulphur, ES), (4) STD (NK) + S_{40} (Single Super Phosphate, SSP), (5) STD (NPK) + S_{40} (Gypsum, Gyp), (6) STD (NPK) + LS spray @ 0.5% after 15–20 DAS, and (7) STD (K) + S_{20} (Ammonium Phosphate Sulphate, APS) + LS spray @ 0.5% after 15–20 DAS revealed that treatment T_7 recorded the highest pod yield (2287 kg ha^{-1}), harvest index (56.6%), and relative agronomic efficiency (RAE) of 140% compared to gypsum. This treatment also gave the maximum net return (Rs. 71,370 ha^{-1}) with a benefit-cost ratio of 1:2.65 and the highest nutrient uptake (65.3 kg N, 33.0 kg P, 80.0 kg K, and 15.4 kg S ha^{-1}). Post-harvest soil analysis indicated improvement in soil pH (5.82) and organic carbon (6.8 g kg^{-1}) over the initial status, with increased availability of P (13.2 kg ha^{-1}), K (232 kg ha^{-1}), and S (17.13 kg ha^{-1}) despite a slight depletion in N. Overall, the combined application of APS (S_{20}) with LS foliar spray @ 0.5% proved to be the most effective practice for enhancing yield, nutrient uptake, soil fertility, and profitability of groundnut cultivation under the Mid-Central Table Land Zone of Odisha.
***Keywords* :** Groundnut, Sulphur sources, Gypsum, Nutrient uptake, Soil fertility.

Introduction

Oilseeds constitute a vital component of the human diet, next only to carbohydrates and proteins. In the Indian economy, oilseeds occupy about 15% of the gross cropped area and contribute nearly 5% to the gross national product, accounting for approximately 7% of global edible oil consumption. Among the various edible oilseed crops grown worldwide, groundnut (*Arachis hypogaea* L.), belonging to the family Leguminosae (Fabaceae), is one of the most important. It is a heavy-feeder crop that thrives in a wide range of soil types and is valued for its nutritional richness, containing about 50% oil, 25–30% protein, 20% carbohydrates, and 5% fiber and ash (Fageria *et al.*, 1997). Groundnut is also a rich source of essential vitamins such as E, K, and B, as well as thiamine and niacin nutrients often limited in cereal-based diets. Owing to its high nutritional and economic value, it is cultivated by millions of smallholder farmers across the world as a major cash crop.

Despite the application of recommended doses of NPK fertilizers, groundnut frequently fails to achieve its yield potential. One of the key reasons for this shortfall is improper nutrient management, particularly the neglect of secondary and micronutrients (e.g., sulphur) (Chahal *et al.*, 2024). With agricultural intensification, the extensive use of straight fertilizers, and the increasing nutrient demands of high-yielding varieties, the deficiency of secondary nutrients such as sulphur (S) has emerged as a significant constraint in achieving sustainable productivity (Solaimalai *et al*., 2024).

Sulphur is an essential nutrient, integral to protein synthesis and oil formation in oilseed crops. It enhances photosynthetic activity, contributes to the formation of glucosides and glucosinolates (which improve oil content), and stabilizes protein structure through the formation of disulphide bonds between polypeptide chains (Sharma *et al*., 2024). Sulphur deficiency has become increasingly common in Indian soils, particularly in coarse-textured alluvial, red, and lateritic soils, as well as leached acidic soils with low organic matter. This widespread deficiency is attributed to reduced atmospheric deposition, replacement of sulphur-containing fertilizers like SSP with DAP, insufficient organic manure application, nutrient removal by high-yielding crops, and strong sulphate adsorption in acid soils (Kundu *et al*., 2020; Chahal *et al*., 2024). The critical limit of sulphur for groundnut has also been recently established, indicating soil and plant S-status must be closely monitored (Kumar *et al*., 2024).

Traditionally, gypsum has served as the primary source of sulphur for oilseed crops. Recent findings demonstrate that timely gypsum application can improve pod yield and quality in groundnut (Kadirimangalam *et al*., 2024). However, its availability has declined in recent years, creating a gap between demand and supply. Therefore, it is imperative to explore and evaluate alternative sulphur sources that are both effective and economically viable for improving groundnut productivity and soil fertility in the Mid-Central Table Land Zone of Odisha.

Materials and Methods

A field experiment was conducted during the *kharif* season of 2021 at the Regional Research and Technology Transfer Station (OUAT), Mahisapat, Dhenkanal district, Odisha, to evaluate the effect of different sulphur sources on yield, nutrient uptake, and soil fertility in groundnut. The experimental site is located at 20°37' N latitude and 85°36' E longitude with an altitude of 328 feet above mean sea level (MSL). The soil of the experimental field was sandy loam in texture, strongly acidic in reaction (pH 5.5), and contained 0.029 dS m^{-1} soluble salts. The initial soil fertility status revealed organic carbon 5.9 g kg^{-1}, $KMnO_4$-extractable N 260 kg ha^{-1}, Bray's-I P 11.8 kg ha^{-1}, NH_4OAc-K 193 kg ha^{-1}, and $CaCl_2$-extractable S 14 kg ha^{-1}, indicating medium levels of N and K and low levels of P and S.

The experiment was laid out in a Randomized Block Design (RBD) with seven treatments and three replications. The details of the treatments were as follows: T_1: Control, T_2: Standard Recommended Dose of Fertilizer (STD), T_3: STD (NPK) + Elemental Sulphur @ 40 kg S ha^{-1}, T_4: STD (NK) + Single Super Phosphate (SSP) @ 40 kg S ha^{-1}, T_5: STD (NPK) + Gypsum @ 40 kg S ha^{-1}, T_6: STD (NPK) + Sulphur as liquid formulation sprayed @ 0.5% at 15–20 DAS, T_7: STD (K) + Ammonium Phosphate Sulphate (APS) @ 20 kg S ha^{-1} + Sulphur liquid formulation sprayed @ 0.5% at 15–20 DAS.

Groundnut was sown in the first week of June following all recommended agronomic practices. A soil test-based fertilizer dose of 25–50–40 kg N–P_2O_5–K_2O ha^{-1} was applied through urea, DAP, and MOP. Half of the nitrogen and the full doses of phosphorus and potassium were applied basally at sowing, while the remaining nitrogen was top-dressed during the first weeding and hoeing operation. Regular intercultural operations such as weeding, hoeing, and thinning were carried out within 20 days after sowing (DAS), and need-based plant protection measures were followed to ensure a healthy crop stand.

The nutrient uptake (kg ha^{-1}) was calculated using the formula given by Pradhan *et al.* (2019):

$$\text{Nutrient Uptake (kg ha}^{-1}) = \frac{\text{Dry Matter (q ha}^{-1}) \times \text{Nutrient Concentration} (\%)}{100}$$

Where

- Nutrient Uptake (kg ha^{-1}): Total amount of nutrient absorbed by the crop.
- Dry Matter (q ha^{-1}): Total dry biomass yield per hectare (in quintals).
- Nutrient Concentration (%): Percentage of the specific nutrient (N, P, K, etc.) in the plant tissue.

The Harvest Index (HI%) was determined following the method of Singh and Stoskopf (1971):

$$\text{Harvest Index} (\%) = \frac{\text{Economic Yield (kg ha}^{-1})}{\text{Biological Yield (kg ha}^{-1})} \times 100$$

The Relative Agronomic Efficiency (RAE) was computed based on total biomass yield using the following formula:

$$\text{RAE} (\%) = \frac{\text{(Biomass yield from sulphur source - Biomass yield in control)}}{\text{(Biomass yield from gypsum source - Biomass yield in control)}} \times 100$$

Statistical analysis of experimental data was performed according to the procedure outlined by Gomez and Gomez (1984) using the Randomized Block Design (RBD) model.

Results and Discussion

Combined Effect of Ammonium Phosphate Sulphate and Liquid Sulphur on Harvest Index (HI %) and Relative Agronomic Efficiency (RAE) of Groundnut

The combined application of Ammonium Phosphate Sulphate (APS) and Liquid Sulphur (LS) significantly influenced pod yield, haulm yield, Harvest Index (HI%), and Relative Agronomic Efficiency (RAE) of groundnut (Table 1). The treatment T_7 [STD (K) + APS @ 20 kg S ha^{-1} + LS spray @ 0.5% twice before and after flowering] recorded the highest pod yield (2287 kg ha^{-1}), haulm yield (1755 kg ha^{-1}), and HI (56.6%) as compared to T_5 [STD (NPK) + Gypsum @ 40 kg S ha^{-1}], which yielded 1961 kg ha^{-1} pods, 1611 kg ha^{-1} haulm, and 54.9% HI. The RAE based on economic yield indicated the superior efficiency of integrating sulphur fertilization with the standard fertilizer dose. The highest RAE (140%) was observed in T_7, whereas the lowest (57%) occurred with the sole application of soil test–based fertilizers without sulphur.

The superior performance of T_7 can be attributed to the balanced nutrient supply from APS (N: 20%, P: 20%, S: 13%) that enhanced nutrient availability during the early growth stages, and the subsequent LS foliar sprays which improved sulphur supply during pod formation and filling stages. This synergistic nutrient management enhanced photosynthesis, protein synthesis, and assimilate partitioning, resulting in higher yield and efficiency. Similar observations were made by Prusty *et al.* (2020), Perumal *et al.* (2019), Singh *et al.* (2021), and Kumar *et al.* (2023), who reported that combined use of soil- and foliar-applied sulphur improved oilseed crop performance, HI, and nutrient use efficiency.

Combined Effect of Ammonium Phosphate Sulphate and Liquid Sulphur on Nutrient Uptake and Post-harvest Soil Properties

Sulphur application significantly enhanced the uptake of macronutrients and secondary nutrients such as N, P, K, S, Ca, and Mg (Tables 2–7). The treatment T_7 [STD (K) + APS @ 20 kg S ha^{-1} + LS spray @ 0.5%] recorded the highest uptake of N (65.3 kg ha^{-1}), K (80 kg ha^{-1}), S (15.4 kg ha^{-1}), Ca (92.0 kg ha^{-1}), and Mg (31.4 kg ha^{-1}), while phosphorus uptake (33 kg ha^{-1}) was at par with T_5 (33.1 kg ha^{-1}). The improved nutrient uptake under T_7 was likely due to enhanced root activity, better nutrient solubility, and improved availability of sulphate ions facilitating the uptake of associated cations. These results corroborate earlier findings by Pattanayak *et al.* (2004), Patel *et al.* (2018), Ramakrishna *et al.* (2017), and recent studies by Sharma *et al.* (2024) and Meena *et al.* (2022), who highlighted sulphur's role in improving nutrient assimilation and yield quality in oilseed crops.

Post-harvest soil analysis (Table 8) showed that sulphur fertilization improved soil pH, organic carbon, and available nutrient content. The T_7 treatment enhanced soil pH (5.82) and organic carbon (6.8 g kg^{-1}) compared to T_5 (pH 5.71; OC 6.5 g kg^{-1}). Although available nitrogen content decreased across treatments, T_7 maintained the highest residual N (229 kg ha^{-1}), suggesting improved N use efficiency due to synergistic N–S interactions. The highest residual available sulphur (18.1 kg ha^{-1}) was recorded under T_3 (Elemental S), followed by T_7 (17.13 kg ha^{-1}), as elemental S releases sulphate gradually through microbial oxidation. These findings align with those of Kundu *et al.* (2020), Rakesh *et al.* (2023), and Sharma *et al.* (2024), who reported improved soil fertility status and nutrient availability with integrated sulphur application strategies.

Table 1: Relative Agronomic Efficiency (RAE) & Harvesting Index (HI%) Groundnut crop as affected by different doses and sources of Sulphur.

Treatments	Pod	Haulm	Total	HI (%)	RAE (%)	B:C Ratio
	<-- kg ha^{-1} -->					
C	1220 (25)**	1180	2400	50.8	–	1.79
S_0	1620	1472	3092	52.4	57	2.13
S_{40} (ES)	2112 (30)***	1704	3815	55.4	121	2.64
S_{40} (SSP)	2035 (26)***	1666	3701	55	111	2.36
S_{40} (Gyp)	1961 (21)***	1611	3572	54.9	100	2.33
S2 (LS)	1786 (10) ***	1547	3333	53.6	80	2.32
S_{20} (APS) + LS	2287 (41)***	1755	4042	56.6	140	2.65
LSD (P= 0.05)	97.8	26.0	454	–	–	–
CV (%)	3.0	9.0	8.0	–	–	–

* RAE was calculated considering total biomass production.
* HI (%) was calculated by pod yield/ total biomass.
** - Data in the parenthesis indicates per cent yield loss no fertilizers application.
*** - Data in the parenthesis indicates per cent yield increased due to sulphur application over no sulphur application

Table 2: Concentration and uptake of nutrients by groundnut crop : Nitrogen

Treatments	Concentration (%)			Uptake (kg ha^{-1})			
	Kernel	Haulm	Husk	Kernel	Haulm	Husk	Total
C	1.44	1.53	1.08	10.5	18.0	5.3	33.8
S_0	1.51	1.59	1.15	15.1	24.4	7.1	46.6
S_{40} (ES)	1.7	1.81	1.35	24.0	30.8	9.3	64.1
S_{40} (SSP)	1.64	1.75	1.31	22.0	29.1	9.1	60.2
S_{40} (Gyp)	1.60	1.70	1.25	20.1	27.4	8.7	56.2
S2 (LS)	1.54	1.62	1.21	17.6	25.1	7.8	50.5
S_{20} (APS) +LS	1.65	1.67	1.28	26.1	29.3	9.9	65.3
LSD(P= 0.05)	0.07	0.07	0.05	0.86	1.30	0.62	11.6

Table 3: Concentration, uptake and recovery of nutrients by groundnut crop : Phosphorus

Treatments	Concentration (%)			Uptake (kg ha^{-1})			
	Kernel	Haulm	Husk	Kernel	Haulm	Husk	Total
C	0.96	0.82	0.94	7.0	9.7	4.7	21.4
S_0	0.94	0.84	0.90	9.5	12.3	5.4	27.2
S_{40} (ES)	1.18	1.00	0.95	16.7	17.0	6.5	40.2
S_{40} (SSP)	1.15	1.01	0.91	15.4	16.8	6.3	38.5
S_{40} (Gyp)	1.08	0.83	0.89	13.6	13.3	6.2	33.1
S2 (LS)	1.08	0.81	0.88	12.3	12.4	5.7	30.4
S_{20} (APS) +LS	1.01	0.82	0.90	14.0	12.7	6.3	33
LSD(P= 0.05)	0.07	0.07	0.08	0.85	1.19	0.59	1.29

Table 4: Concentration, uptake and recovery of nutrients by groundnut crop : Potassium

Treatments	Concentration (%)			Uptake (kg ha^{-1})			
	Kernel	Haulm	Husk	Kernel	Haulm	Husk	Total
C	2.18	2.12	0.93	15.9	25.0	4.6	46.0
S_0	2.20	2.18	0.98	22.0	32.0	6.0	60.0
S_{40} (ES)	2.28	2.31	1.12	32.4	39.3	7.8	79.5
S_{40} (SSP)	2.26	2.28	1.07	30.2	38.0	7.5	75.7
S_{40} (Gyp)	2.16	2.24	1.03	27.2	36.1	7.2	70.5
S2 (LS)	2.22	2.24	1.01	25.3	34.6	6.6	66.5
S_{20} (APS) +LS	2.20	2.1	1.08	34.8	37.7	7.5	80.0
LSD(P= 0.05)	0.08	0.04	0.49	1.44	0.93	0.66	15.8

Table 5: Concentration and uptake of nutrients by groundnut crop: Sulphur

Treatments	Concentration (%)			Uptake (kg ha^{-1})			
	Kernel	Haulm	Husk	Kernel	Haulm	Husk	Total
C	0.18	0.18	0.12	1.3	2.1	0.6	4.0
S_0	0.22	0.21	0.14	2.2	3.1	0.9	6.2
S_{40} (ES)	0.35	0.37	0.30	4.9	6.3	2.1	13.3
S_{40} (SSP)	0.32	0.33	0.27	4.3	5.5	1.9	11.7
S_{40} (Gyp)	0.28	0.28	0.25	3.5	4.5	1.7	9.7
S2 (LS)	0.24	0.25	0.17	2.8	3.9	1.1	7.8
S_{20} (APS) +LS	0.38	0.39	0.35	6.0	6.9	2.5	15.4
LSD (P= 0.05)	0.05	0.04	0.03	0.63	0.07	0.28	3.10

Table 6: Concentration and uptake of nutrients by groundnut crop : Calcium

Treatments	Concentration (%)		Uptake (kg ha^{-1})		
	Kernel	Haulm	Kernel	Haulm	Total
C	1.54	2.74	11.21	32.32	43.5
S_0	2.07	3.11	20.70	45.60	66.3
S_{40} (ES)	2.23	3.01	31.74	51.30	83.0
S_{40} (SSP)	2.57	3.09	34.30	51.45	85.8

S_{40} (Gyp)	2.40	2.40	36.27	38.65	68.9
S2 (LS)	0.34	3.09	3.86	47.81	51.7
S_{20} (APS)+LS	2.60	2.90	41.1	50.9	92.0
LSD (P=0.05)	0.02	0.22	1.20	0.34	1.31

Table 7: Concentration and uptake of nutrients by groundnut crop : Magnesium

Treatments	Concentration (%)		Uptake (kg ha^{-1})		
	Kernel	Haulm	Kernel	Haulm	Total
C	1.0	0.89	7.30	10.50	18.0
S_0	1.2	2.03	12.04	29.90	42.0
S_{40} (ES)	1.5	1.50	21.46	25.56	47.0
S_{40} (SSP)	1.4	1.61	18.70	26.81	45.5
S_{40} (Gyp)	1.4	1.71	17.66	27.54	45.2
S2 (LS)	1.51	1.71	17.17	26.46	43.6
S_{20} (APS) + LS	0.89	0.99	14.05	17.37	31.4
LSD (P= 0.05)	0.02	0.01	0.63	0.34	0.71

Table 8: Effect of different S sources practices on post-harvest soil pH, Organic carbon, EC, available nutrients N, P, K and S.

Treatments	pH	OC (g kg^{-1})	Available nutrients (kg ha^{-1})			
			N	P	K	S
Initial	5.5	5.9	260	11.8	193	14
C	5.2	5.5	154	9.2	174	9.23
S_0	5.32	5.8	183	10.33	188	10.73
S_{40} (ES)	5.78	6.6	220	12.4	224	18.10
S_{40} (SSP)	5.68	6.2	208	11.73	202	15.67
S_{40} (Gyp)	5.71	6.5	212	12.07	211	16.33
S2 (LS)	5.64	6.0	191	11.2	193	14.6
S_{20} (APS) +LS	5.82	6.8	229	13.2	232	17.13
CD (P=0.05)	0.08	0.05	14.22	0.60	11.17	0.73

Conclusion

From the present experiment, it can be concluded that ammonium phosphate sulphate, followed by elemental sulphur and single super phosphate, proved to be effective alternatives to gypsum as sulphur sources for groundnut cultivation. Under adverse conditions, the use of liquid sulphur formulations as foliar sprays also showed potential benefits. The uptake of major nutrients nitrogen (N), potassium (K), and sulphur (S) was significantly enhanced under the proposed practice, being 16.2%, 13.5%, and 58.8% higher, respectively, compared to gypsum application, corresponding to 56.2 kg N, 70.5 kg K, and 9.7 kg S ha^{-1}. The uptake of phosphorus (P) (33.1 kg ha^{-1}) remained statistically at par with gypsum treatment. Furthermore, post-harvest soil properties were found to be favorable under the proposed practice, exhibiting improvements in soil pH, organic carbon content, and available nutrient status, indicating a sustainable and soil-health–promoting nutrient management approach for groundnut cultivation.

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