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Evaluation of Sulphur Sources on Yield, Economics, and Apparent Nutrient Recovery in Groundnut Crop under the Mid-Central Table Land Zone of Odisha

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Abstract
A field experiment was conducted at the Regional Research and Technology Transfer Station (OUAT), Mahisapat, Dhenkanal district, during the kharif season of 2021 to evaluate the effect of different sulphur sources on groundnut in the Mid-Central Table Land Zone of Odisha. The experiment was laid out in a randomized block design with three replications and seven treatments, namely: (1) Control, (2) STD (NPK) + S_0, (3) STD (NPK) + S_{40} (elemental sulphur), (4) STD (NK) + S_{40} (single super phosphate), (5) STD (NPK) + S_{40} (gypsum), (6) STD (NPK) + liquid sulphur spray @ 0.5% at 15-20 DAS, and (7) STD (K) + S_{20} (ammonium phosphate sulphate) + liquid sulphur spray @ 0.5% at 15-20 DAS. Among the seven treatments, STD (K) + S_{20} (APS) + LS spray @ 0.5% at 15-20 DAS recorded superior performance in terms of growth and yield attributes such as plant height (48.2 cm), growth rate (5.3 mm day^{-1}), number of branches (9.9), number of pods per plant (21), and shelling percentage (69.2). The total pod yield obtained under this treatment was 2287 kg ha^{-1}. Sulphur management significantly enhanced nutrient uptake, resulting in the highest removal of 65, 33, 80, and 15.4 kg ha^{-1} of N, P, K, and S, respectively, along with an additional nitrogen gain of 31.5 kg ha^{-1}, maximum phosphorus recovery (53.5%), potassium recovery (75%), and sulphur recovery (33%) compared to the gypsum source (56.2 kg N ha^{-1}, 33 kg P ha^{-1}, 70.5 kg K ha^{-1}, and 9.7 kg S ha^{-1} with respective recoveries of 22.4%, 29.2%, 49.5%, and 11%). Economically, this treatment recorded the highest net return of ₹71,370 ha^{-1} with a benefit-cost ratio of 2.65, indicating a return of ₹2.65 per rupee invested.

Keywords: Groundnut, sulphur sources, nutrient uptake, yield, economics

Introduction

Oilseeds constitute an essential component of the human diet, next only to starch and protein. In the Indian economy, oilseeds account for about 15% of the gross cropped area and contribute approximately 5% to the gross national product and 7% to global edible-oil consumption (Solaimalai *et al.*, 2022). Among edible oilseed crops, groundnut (*Arachis hypogaea* L.) is one of the most important, belonging to the family Fabaceae. Because of its high oil content, groundnut is regarded both as a grain legume and an oilseed crop. It is a heavy feeder and can be cultivated in a wide range of soils. Groundnut seeds contain about 50% oil, 25-30% protein, 20% carbohydrates, and 5% fibre and ash, making it a rich source of nutrition (Narayan *et al.*, 2023) [12]. It is also an excellent source of vitamins E, K and B, along with thiamine and niacin, which are less abundant in cereals (Kumari *et al.*, 2024) [6].

The intensification of agriculture, continuous use of straight fertilizers, and increasing nutrient demand of high-yielding crops have accentuated the need for managing secondary and micronutrients, which are now emerging as major constraints to sustaining soil fertility and productivity (Management of Plant Nutrients, 2024). Globally, the major groundnut-producing countries include India, China, Nigeria, Senegal, Sudan, Myanmar, and the United States, which together account for nearly 69% of the total cultivated area (18.9 million ha) and 70% of global production (17.8 million t) (Gautam, 2025) [2]. India ranks first in both area (~7.5 million ha) and production (~6 million t annually) of groundnut.

Sulphur (S) is a vital plant nutrient, being an essential constituent of proteins and playing a key role in oil synthesis. Its requirement is particularly critical in groundnut, which is rich in both oil and protein (Chahal *et al.*, 2024) [1]. Supplementation with sulphur enhances photosynthetic activity and improves haulm and pod yield (Monika *et al*., 2024; Nayak *et al*., 2023) [10, 13]. Sulphur also contributes to the formation of glucosides or glucosinolates, which upon hydrolysis promote oil accumulation in oilseed crops. In proteins or polypeptides, sulphur facilitates the formation of disulphide bonds, thus stabilizing molecular structure (Narayan *et al*., 2023) [12].

Sulphur deficiency has become increasingly widespread in Indian soils—especially in coarse-textured alluvial soils, red and lateritic soils, leached acidic soils, and soils with low organic-matter content. This deficiency is largely attributed to reduced atmospheric S inputs, replacement of single super phosphate (SSP) by diammonium phosphate (DAP), declining organic-matter levels, inadequate use of organic manures, higher crop removal under intensive cultivation, and sulphur adsorption in acidic soils (Kumar *et al*., 2019; Kundu *et al*., 2020) [5, 7]. Recent research indicates that integrated S-management through combined use of soil and foliar sulphur sources significantly improves oil content, nutrient-use efficiency, and profitability of groundnut under Indian conditions (Kolape *et al*., 2024; The Importance of Sulphur in Oilseed Production, 2025).

Materials and Methods

The field experiment was conducted during the kharif season of 2021 at the Regional Research and Technology Transfer Station (OUAT), Mahisapat, Dhenkanal district, Odisha. 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. The soil of the experimental field was sandy loam in texture, strongly acidic in reaction (pH 5.5), and had a soluble salt content of 0.029 dS m^{-1}. The soil was medium in organic carbon (5.9 g kg^{-1}), $KMnO_4$-extractable nitrogen (260 kg ha^{-1}), and NH_4OAc-extractable potassium (193 kg ha^{-1}), but low in Bray's-I phosphorus (11.8 kg ha^{-1}) and $CaCl_2$-extractable sulphur (14 kg ha^{-1}).

The experiment was laid out in a Randomized Block Design (RBD) with seven treatments and three replications. The treatment details were as follows: T_1 - Control, T_2 - Standard dose (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 (liquid formulation) sprayed @ 0.5% at 15-20 DAS, T_7 - STD (K) + Ammonium phosphate sulphate @ 20 kg S ha^{-1} + Sulphur (liquid formulation) sprayed @ 0.5%.

Groundnut (*Arachis hypogaea* L.) was sown during the first week of June following the recommended package of practices. The crop received a soil test-based fertilizer dose of N-P_2O_5-K_2O @ 25-50-40 kg ha^{-1} through urea, DAP, and MOP. Fifty percent of nitrogen and the full dose of phosphorus and potassium were applied as a basal dose at the time of sowing, while the remaining 50% nitrogen was top-dressed during the first weeding and hoeing operation. Hand weeding, hoeing, and thinning were carried out within 20 days after sowing. Plant protection measures were undertaken as and when required to maintain a healthy crop stand.

Statistical analysis of the data was carried out following the procedures described by Gomez and Gomez (1984).

Results and Discussion

Combined Effect of Ammonium Phosphate Sulphate and Liquid Sulphur on Growth and Yield Attributes of Groundnut

The combined application of ammonium phosphate sulphate (APS) and liquid sulphur (LS) significantly influenced growth and yield attributes 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 plant height (48.2 cm), growth rate (5.3 mm day^{-1}), number of branches per plant (9.9), and number of pods per plant (21). This was followed by T_5 [STD (NPK) + Gypsum @ 40 kg S ha^{-1}], which recorded a plant height of 38.6 cm, growth rate of 4.3 mm day^{-1}, 8.3 branches per plant, and 19 pods per plant.

The superior performance of T_7 may be attributed to APS, a multi-nutrient fertilizer containing N (20%), P (20%), and S (13%), which supplies all essential nutrients in a balanced manner when applied as basal. This ensures adequate nutrient availability throughout the crop growth stages, particularly during flowering and pod development. The subsequent foliar application of LS effectively met the crop's late-stage sulphur requirements, enhancing growth and pod development. Similar results were reported by Prusty *et al*. (2020) [16], Perumal *et al*. (2019) [15], and Rao *et al*. (2013) [17], who observed that different sulphur sources significantly improved growth and yield traits in oilseed crops.

Combined Effect on Yield and Economics

Treatment T_7 produced the highest pod yield (22.87 q ha^{-1}), registering a yield advantage of 41% over the standard dose (STD) and 17% over T_5, which recorded 19.61 q ha^{-1}. The highest shelling percentage (69.2%) was also noted in T_7 compared to 64.6% in T_5. The increase in pod yield and shelling percentage could be attributed to higher photosynthetic activity and nutrient uptake, which improved pod filling and kernel development. These findings are in agreement with Hamakareem *et al*. (2016) [3] and Parmar *et al*. (2018) [14].

Balanced and judicious application of sulphur through APS (as basal) and LS (as foliar spray at 15 DAS) ensured adequate S supply throughout the crop growth stages. This integrated approach prevented sulphur deficiency and improved nutrient balance, resulting in enhanced yield and profitability compared to other sources such as gypsum. Similar findings were reported by Najar *et al*. (2011) [11] and Singh *et al*. (2020) [18], who highlighted the role of sulphur in promoting flowering, nodulation, and oil quality in groundnut.

The maximum benefit-cost ratio (2.65) was obtained in T_7, followed by T_5 (2.33), while the control recorded the lowest value (1.79). The B:C ratio among treatments followed the order:

APS + LS > Elemental S > SSP > Gypsum > LS > Control.

Effect on Nitrogen Gain and Apparent Nutrient Recovery

Sulphur supplementation markedly improved apparent nutrient recovery and biological nitrogen fixation in groundnut (Table 2). The extra nitrogen gain ranged from 12.8 to 31.5 kg ha^{-1}, with the highest gain (31.5 kg ha^{-1}) recorded under T_7, followed by T_3 (Elemental S @ 40 kg ha^{-1}) with 30.3 kg ha^{-1}. This enhancement may be attributed to the synergistic effect of sulphur in promoting nodulation and N_2 fixation.

Apparent recovery of phosphorus was also highest under T_7 (53.5%), followed by T_3 (47.6%), indicating better utilization of applied P due to improved root growth and enzymatic activity. Similarly, apparent recovery of potassium and sulphur in pods was maximum under T_7 (31.5% and 75%, respectively), followed by T_5 (30.3% and 67.7%). These results corroborate the findings of Jat *et al.* (2010), who reported progressive improvement in apparent recovery with sulphur application across oilseed crops.

Table 1: Yield and yield attributing characters of Groundnut as affected by different doses and sources of Sulphur

Treatments	Plant height (cm)	Growth rate (mm day-1)	No of branches/ Plant	No of pods/plant	Pod Yield	Increase in yield	Shelling (%)	B:C Ratio
C	30.4	3.3	4.4	8	1220	_	60	1.79
S0	33.2	3.4	6.2	13	1620	32.8	63	2.13
S40 (ES)	44.1	3.7	8.9	20	2112	73.1	67.6	2.64
S40 (SSP)	41.3	4.9	7.8	18	2035	66.8	65.7	2.36
S40 (Gyp)	38.6	4.3	8.3	19	1961	60.74	64.6	2.33
S2 (LS)	36.0	4.0	7.2	16	1786	46.4	63.7	2.32
S20 (APS) + LS	48.2	5.3	9.9	21	2287	87.5	69.2	2.65
LSD(P= 0.05)	1.14	1.12	0.42	0.65	97.8		1.6	

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

Treatments	Concentration (%)			Uptake (kg ha^{-1})				Extra N Gain (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	12.8
S_{40} (ES)	1.7	1.81	1.35	24.0	30.8	9.3	64.1	30.3
S_{40} (SSP)	1.64	1.75	1.31	22.0	29.1	9.1	60.2	26.4
S_{40} (Gyp)	1.60	1.70	1.25	20.1	27.4	8.7	56.2	22.4
S2 (LS)	1.54	1.62	1.21	17.6	25.1	7.8	50.5	16.7
S_{20} (APS) + LS	1.65	1.67	1.28	26.1	29.3	9.9	65.3	31.5
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})				APR (%)
	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	14.7
S_{40} (ES)	1.18	1.00	0.95	16.7	17.0	6.5	40.2	47.6
S_{40} (SSP)	1.15	1.01	0.91	15.4	16.8	6.3	38.5	41.9
S_{40} (Gyp)	1.08	0.83	0.89	13.6	13.3	6.2	33.1	29.2
S2 (LS)	1.08	0.81	0.88	12.3	12.4	5.7	30.4	22.8
S_{20} (APS) + LS	1.01	0.82	0.90	14.0	12.7	6.3	33	53.5
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})				AKR (%)
	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	28.3
S_{40} (ES)	2.28	2.31	1.12	32.4	39.3	7.8	79.5	67.7
S_{40} (SSP)	2.26	2.28	1.07	30.2	38.0	7.5	75.7	60.0
S_{40} (Gyp)	2.16	2.24	1.03	27.2	36.1	7.2	70.5	49.5
S2 (LS)	2.22	2.24	1.01	25.3	34.6	6.6	66.5	41.4
S_{20} (APS) + LS	2.20	2.1	1.08	34.8	37.7	7.5	80.0	75.0
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})				ASR (%)
	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	17.6
S_{40} (ES)	0.35	0.37	0.30	4.9	6.3	2.1	13.3	17.7
S_{40} (SSP)	0.32	0.33	0.27	4.3	5.5	1.9	11.7	14.7
S_{40} (Gyp)	0.28	0.28	0.25	3.5	4.5	1.7	9.7	11.0
S2 (LS)	0.24	0.25	0.17	2.8	3.9	1.1	7.8	26.0
S_{20} (APS) + LS	0.38	0.39	0.35	6.0	6.9	2.5	15.4	33.0
LSD (P= 0.05)	0.05	0.04	0.03	0.63	0.07	0.28	3.10	

Conclusion

From the present investigation, the following conclusions were drawn:

Among different sulphur sources, ammonium phosphate sulphate (APS) proved most effective, followed by elemental sulphur and single super phosphate (SSP) as solid fertilizers. Liquid sulphur (LS) also showed potential as a foliar supplement under stress or adverse conditions.

Application of APS @ 20 kg S ha^{-1} as basal along with a foliar spray of LS @ 0.5% at 15 DAS (before flowering) and soil test-based K resulted in the highest pod yield (2287 kg ha^{-1}) and shelling percentage (69.2%), representing a 17% yield increase over gypsum (1961 kg ha^{-1}, 64.6% shelling).

The integrated use of APS and LS enhanced nutrient recovery, nitrogen fixation, and overall profitability, indicating that this combination can effectively replace gypsum as a sulphur source for groundnut cultivation in the Mid-Central Table Land Zone of Odisha.

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