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Research Paper

Sulphur management in rice (*Oryza sativa*)–groundnut (*Arachis hypogaea*) to boost crop growth and system productivity

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ABSTRACT

Nearly 44% soils in India and 36% soils in Odisha are deficient in sulphur (S). Both rice and groundnut respond well to S application. A field experiment comprising five sulphur fertilization methods, viz. no sulphur, 20 kg S/ha as bentonite sulphur, 20 kg S/ha as gypsum, 40 kg S/ha as bentonite sulphur and 40 kg S/ha as gypsum in rice allocated to main plots and three sulphur levels, viz. 0, 30 and 60 kg S/ha in groundnut allocated to subplots was conducted in a split-plot design with four replications during the *kharif and rabi* seasons of 2021–22 and 2022–23 at Bhubaneswar, India to assess the response of sulphur application on rice-groundnut system to. Application of 40 kg S/ha as gypsum to rice registered 24.2% grain yield increment (4.81 t/ha) over no sulphur. Likewise, in groundnut, an 18.4% yield increment was recorded with the application of 60 kg S/ha (2.05 t/ha) over no sulphur. Combined application of 40 kg S/ha as bentonite sulphur in rice + 60 kg S/ha in groundnut recorded the maximum system rice equivalent yield (11.21 t/ha), keeping 40 kg S/ha as gypsum in rice + 60 kg S/ha in groundnut at par. Rice grain yield and groundnut pod yield exhibited a significant positive correlation with dry matter accumulation and yield attributes of respective crops. Overall findings inferred that farmers should apply 40 kg S/ha as bentonite sulphur or gypsum in rice along with 60 kg S/ha in groundnut to boost crop growth and maximize system productivity in sulphur-deficient soils of Eastern India.

Key words: Bentonite, Correlation, Gypsum, Haulm yield, Rice equivalent yield

Rice serves as the primary dietary energy source for many Indians and is a staple food for nearly half of the world's population (Jena *et al.,* 2021). Rice-based cropping system predominates in the state of Odisha, situated in Eastern India and groundnut, as an oilseed crop, is a better fit in the system (Mohapatra *et al.,* 2022). The practice of continuous rice monocropping and heavy reliance on chemical fertilizers deteriorate soil quality. Transitioning to a rice-legume cropping system can address this issue. It is beneficial to adopt suitable rice-based cropping systems and nutrient management strategies to achieve higher yields while preserving soil fertility (Samant *et al.,* 2023). Sulphur (S) is considered as the fourth most essential nutrient, following nitrogen, phosphorus, and potassium, and it plays a crucial role in crop production (Mishra *et al.,* 2022). S is involved in essential metabolic activities in plants, including the synthesis of sulphur-containing amino acids and vitamins (thiamine and biotin), iron-sulphur protein complex, ferredoxin sulphur glycosides and co-enzyme-A (Prasad and Shivay*,* 2018; Jez, 2019). Its deficiency is quickly emerging in areas under oilseeds and pulses due to the higher removal of sulphur by these crops (Shivay *et al*., 2014; Bhudevi *et al.*, 2018). The reasons for deficiencies are no or low application of sulphur-containing fertilizers, intensive cropping patterns, and minimal utilization of sulphur fungicides (Narayan *et al.,* 2023). Sulphur deficiency negatively impacts plant growth phases, yield attributes and ultimately reduces rice yield (Islam *et al.,* 2016). In the case of groundnut, S enhances the yield attributing characters and ultimately, the yield (Dileep *et al.,* 2021). Nearly 44% soils in India and 36% soils in Odisha are deficient in S (Ram *et al.,* 2017; Mishra *et al.,* 2022). Sulphur is crucial in increasing the crop productivity of legumes and oilseeds (Noman *et al.*, 2020; Rathore *et al.,* 2024). Different researchers across the globe conducted several studies that established the role of S in

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enhancing growth parameters, yield contributing characters, and yield of crops (Noman *et al.*, 2020; Mishra *et al.,* 2022). Plant nutrients applied to *kharif* rice are not fully utilized and have carry-over effect for the succeeding crop (Samant *et al.*, 2023). The sulphur sources, namely, gypsum (a readily available form of sulphur) and bentonite sulphur (a slowly available form of sulphur) differ for relative efficacy in enhancing growth and yield of crops in rice-groundnut cropping system through direct and residual effects. Under these circumstances, a field experiment comprising S fertilization methods in rice and S levels in groundnut was carried out with hypothesis that the treatments would ensure adequate S availability in soil for the cropping system, improve growth parameters and yield attributes of component crops and maximize productivity of the sequence cropping system.

MATERIALS AND METHODS

A field experiment was conducted during the *kharif* and *rabi* seasons of 2021–22 and 2022–23 at the Agricultural Research Station (20° 26'N; 85° 68'E and 50.9 m above mean sea level), Chhatabar, Siksha 'O' Anusandhan (Deemed to be) University, Bhubaneswar, Odisha, India. The experimental site is situated in the East and South-Eastern Coastal Plain agro-climatic zone of Odisha. The soil of the experimental site was clay loam in texture, acidic in nature (pH 5.82), low in electrical conductivity (0.45 dS/m), low in organic carbon (0.4%), medium in available nitrogen (288.6 kg/ha), medium in available phosphorus (18.54 kg/ha), medium in potassium (210 kg/ha) and low in sulphur (8.7 ppm). The soil was analysed to determine texture, pH, electrical conductivity, organic carbon, available nitrogen, available phosphorus, available potassium and available sulphur with the methodology proposed by Bouyoucos (1962), Jackson (1973), Jackson (1973), Walkley and Black (1934), Subbiah and Asija (1956), Jackson (1973), Jackson (1973) and Chesnin and Yien (1950), respectively. The experiment comprising five sulphur fertilization methods in rice, viz. F_1, no sulphur; F_2, 20 kg S/ha as bentonite sulphur; F_3, 20 kg S/ha as gypsum; F_4, 40 kg S/ha as bentonite sulphur and F_5, 40 kg S/ha as gypsum allocated to the main plots and three levels (kg/ha) of sulphur as bentonite sulphur, viz. L_1, 0 (no sulphur); L_2, 30 and L_3, 60 allocated to the subplots was conducted in split plot design with four replications. The sources of sulphur were gypsum of agricultural grade (16% S) and bentonite sulphur (90% S). The source of nitrogen was urea (46% N) and di-ammonium phosphate (18% N), while phosphorus and potassium requirement was met through di-ammonium phosphate (46% P_2O_5) and muriate of potash (60% K_2O), respectively. Rice cv. '*Naveen*' and groundnut cv. '*Devi*' were used as test crops in the experiment. Nursery sowing in rice was done on 25th June 2021 and 24th June 2022, while, transplanting was done on 18th July 2021 and 17th July 2022 with spacing 20 cm × 10 cm with 2-3 seedlings/hill. The rice crop was grown with Farm Yard Manure @ 5 tonne/ha along with 80-40-40 kg N-P_2O_5-K_2O/ha. The sulphur was applied basal as per treatment specifications. Weed was managed by applying pretilachlor @ 0.75 kg/ha (pre-emergence) followed by one hand weeding at 21 days after transplanting (DAT). The rice was raised as a rainfed crop and harvested on 24th October and 22nd October in the 1st and the 2nd year, respectively. Plot-wise grain weight was recorded at 12% moisture content and converted to t/ha. Groundnut crop was sown on 18th November 2021 in the 1st year and 20th November 2022 in the 2nd year with seed rate of 175 kg pod/ha (125 kg kernel/ha), spacing of 25 cm × 10 cm and fertilizer dose of 20–40–40 kg N-P_2O_5-K_2O/ha applied as basal. Sulphur was applied basally as per the treatment through bentonite sulphur. Weed management was done by application of pendimethalin @ 1 kg/ha followed by two manual weeding at 22 and 58 days after sowing (DAS). Groundnut crop was harvested on 1st March 2022 and 2nd March 2023, when the plants turned yellow, leaves started drying, and pods developed blackish streaks inside the pods. Plot-wise pod weight was recorded at moisture content of 10% and converted to t/ha. Periodic dry matter accumulation was recorded by sun-drying of plant samples followed by oven drying at 70°C until a constant weight was achieved. The crop growth rate (CGR) and relative growth rate (RGR) were worked out using the formula proposed by Radford (1967).

$$\text{CGR (g/m}^2\text{/day)} = \frac{W_2 - W_1}{T_2 - T_1}$$

$$\text{RGR (g/g/day)} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

Where, W_1 and W_2 are the dry matter production g/m^2 at time T_1 and T_2, respectively.

The calculated RGR values were expressed as mg/g/day for better readability. The shelling percentage of groundnut was calculated by using the following formulae

$$\text{Groundnut shelling \%} = \frac{\text{Kernel weight(g)}}{\text{Pod weight (g)}} \times 100$$

The productivity of the rice-groundnut cropping system was expressed as rice equivalent yield (REY).

$$\text{System REY (t/ha)} = \text{Yield of rice(t/ha)} + \text{Yield of groundnut(t/}ha\text{)} \times \frac{\text{MSP of groundnut}}{\text{MSP of rice}}$$

The Minimum Support Price (MSP) of rice was ₹19,400 and ₹20,400/t, while in case of groundnut it was ₹55,500 and ₹58,500/t in 202–22 and 2022–23, respectively.

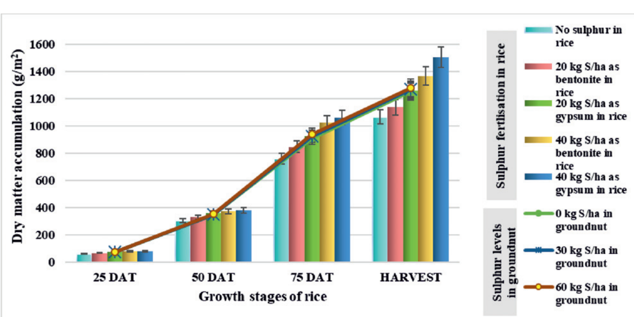
The data collected from the field was subjected to statistical analysis (Gomez and Gomez,1984). The data was subjected to pooled analysis, when the error variances of both the years (2021–22 and 2022–23) were homogeneous as indicated by Bartlett's Test.

RESULTS AND DISCUSSION

Effect of sulphur management on rice

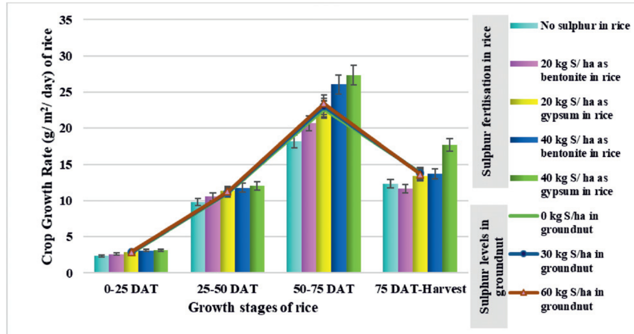
Growth parameters

Among the different sulphur fertilization methods, application of 40 kg of S/ha as gypsum in rice recorded the highest dry matter accumulation of 78.4, 378.5, 1061.3 and 1504.1 g/m^2 at 25, 50, 75 DAT and at harvest, respectively (Fig. 1) and proved significantly superior to other sulphur fertilization methods. The increase in dry matter accumulation in rice due to sulphur fertilization was due to involvement of sulphur in enhancement of chlorophyll content, synthesis of sulphur-containing amino acids and activation of enzymes that contributed to a higher rate of photosynthesis. Ram *et al.* (2014) reported higher dry matter accumulation with gypsum @ 60 kg S/ha over no sulphur, application of gypsum and phospho-gypsum at 30 kg/ha. The residual effect of 60 kg S/ha applied to groundnut recorded the maximum rice dry matter accumulation of 71.9, 352.9, 937.7 and 1278.4 g/m^2 at 25, 50, 75 DAT and at harvest, respectively, in rice (Fig.1) and proved significantly superior to 30 kg S/ha and no sulphur. The maximum dry matter of rice due to maximum dose of sulphur applied to groundnut was due to partial utilization of sulphur by groundnut and carry-over effect on the succeeding rice. Ram *et al.* (2017) reported a significant increase in dry matter accumulation of rice due to 30 kg S/ha applied to the preceding crop. Application of 40 kg of S/ha as gypsum in rice recorded CGR values of 3.14, 12.0, 27.32 and 17.71 g/ m^2/ day at 0–25, 25–50, 50–75 DAT and 75 DAT- harvest, respectively and proved superior to other sulphur fertilisation methods (Fig. 2), revealing higher dry matter accumulation with higher level of sulphur at different stages of crop growth. Similar type variation in CGR due to integration of rice cultivars with nitrogen management practices was reported by Behera *et al.* (2022). Application of 60 kg S/ha to groundnut produced significantly higher



DAT- Days after transplanting; S- sulphur; ha- hectare

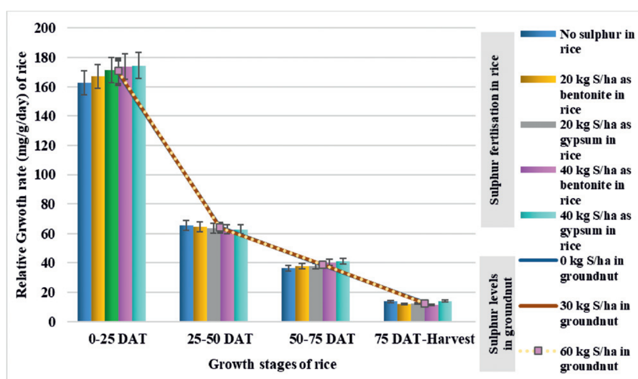
Fig. 1. Effect of sulphur management on dry matter accumulation of rice under rice-groundnut cropping system



DAT- Days after transplanting; S- sulphur; ha- hectare

Fig. 2. Effect of sulphur management on growth rate of rice under rice-groundnut cropping system

CGR values, viz. 2.87 11.24, 23.39 and 13.62 g/m^2/ day at 0–25, 25–50, 50–75 DAT and 75 DAT-harvest, respectively. Ram *et al.* (2017) reported significant residual effects on CGR of wheat due to application of sulphur to preceding rice at 60 kg/ha. Application of 40 kg S/ha as gypsum in rice produced significantly higher RGR values, viz.174.4, 63.0, 41.2 and 13.9 mg/g/day at 0–25, 25–50, 50–75 DAT and 75 DAT- harvest, respectively (Fig. 3). Carry-over effects of 60 kg S/ha applied to groundnut recorded significantly higher RGR *viz.*, 170.7, 63.8, 38.9 and 12.4 mg/g/day at 0–25, 25–50, 50–75 DAT and 75 DAT-harvest, respectively, than other S levels. A gradual decline in RGR values was observed with the advancement of crop growth consequent to development of reproductive parts (sink). The decline in RGR with the advancement of growth in conformity with Chandrika *et al.* (2015) and Behera *et al.* (2022).



DAT- Days after transplanting; S- sulphur; ha- hectare

Fig. 3. Effect of sulphur management on relative growth rate of rice under rice-groundnut cropping system

Yield attributes

Application of 40 kg of S/ha as gypsum in rice produced the highest number of effective tillers/hill (11.4), panicle length (23.5 cm), spikelets/panicle (152.5), filled grains/

panicle (138.2) and test weight of 1000 grains (24.73 g), keeping 40 kg S/ha as bentonite sulphur at par (Table 1) and proved significantly superior to all other sulphur fertilization methods in rice. The superior yield attributes under 40 kg of S/ha as gypsum and bentonite sulphur may be attributed to availability of adequate sulphur, enhanced synthesis of sulphur-containing amino acids, and better crop growth. Singh *et al*. (2016) reported the maximum values of panicle length, grains/panicle, test weight of rice with the application of 45 kg S/ha. Residual effect of 60 kg S/ha applied to groundnut produced significantly higher values of yield attributes of rice, viz. effective tillers/hill (10.0), panicle length (22.7 cm), spikelets/panicle (147.2), filled grains/panicle (134.2) and 1,000-grain weight (24.59 g) than control (no sulphur), keeping 30 kg S/ha at par (Table 1). The carry-over effects of sulphur were due to partial utilisation of applied S by groundnut crop and leaving the rest for use by succeeding rice. Similar kind of finding on residual effect of nutrients was reported by Samant *et al*. (2023).

Productivity

Application of 40 kg of S/ha as gypsum produced the highest grain yield (4.81 t/ha) and straw yield (7.02 t/ha), keeping 40 kg S/ha as bentonite sulphur at par in (Table 2). All other sulphur fertilization practices in rice produced significantly less yields. Fertilisation with 40 kg S/ha as gypsum and bentonite sulphur enhanced the grain yield by 24.3 and 20.4%, respectively, over no sulphur application. The experimental soil was deficient in sulphur. Application of 40 kg S/ha either as gypsum or bentonite sulphur ensured adequate sulphur availability to rice that facilitated synthesis of S-containing amino acids in plant, enhanced growth parameters, dry matter accumulation and crop growth rate and increased yield attributes. Yield and yield attributing characters are functionally related. Hence, these two-sulphur fertilization methods recorded the highest grain and straw yield than the rest in rice. Earlier, Shivay *et al.* (2014) reported higher yield of rice with application of 45 kg S/ha. The residual effect of 60 kg S/ha applied to groundnut recorded the maximum grain yield (4.50 t/ha) and straw yield (6.58 t/ha), keeping 30 kg S/ha at par. The findings agree with Samant *et al*. (2023) who reported positive effects of carry-over nutrients on the succeeding crops. The interaction effects of sulphur fertilization in rice and sulphur levels in groundnut were found to be significant on the grain and straw yield of rice (Table 2). Among the treatment combinations, 40 kg of S/ha as gypsum to rice and 60 kg of S/ha to groundnut (F_4L_3) produced the highest grain yield (4.90 t/ha) and straw yield (7.12 t/ha), being at par with combined application of 40 kg of S/ha as gypsum or bentonite sulphur in rice and 30 kg of S/ha in groundnut (F_4L_2) and (F_5L_2).

Effect of sulphur management on groundnut

Growth parameters

Application of 40 kg S/ha as bentonite sulphur in rice recorded the maximum dry matter accumulation of 23.6, 221.1, 542.7 and 768.2 g/m^2 at 30, 60, 90 DAS and harvest, respectively in groundnut and proved better than other sulphur management practices (Fig. 4). It was due to slow-release nature of bentonite sulphur (40 kg S/ha) that con-

Table 1. Effect of sulphur management on yield attributes of rice under rice-groundnut cropping system

Treatment	Effective tillers/ hill	Panicle length (cm)	Spikelets/ panicle	Filled grains/ panicle	1000- grain weight (g)
Sulphur fertilization in rice					
F_1, No sulphur	7.5	20.7	137.3	125.5	24.14
F_2, 20 kg S/ha as bentonite	8.1	21.8	142.0	130.0	24.25
F_3, 20 kg S/ha as gypsum	9.0	22.4	145.7	132.4	24.42
F_4, 40 kg S/ha as bentonite	10.5	22.9	149.9	135.8	24.69
F_5, 40 kg S/ha as gypsum	11.4	23.5	152.5	138.2	24.73
SEm±	0.28	0.21	1.39	1.55	0.10
CD (P=0.05)	0.81	0.62	4.06	4.52	0.28
Sulphur levels (kg S /ha) in groundnut					
L_1, 0	8.5	21.6	143.2	130.3	24.30
L_2, 30	9.4	22.4	146.0	132.8	24.46
L_3, 60	10.0	22.7	147.2	134.2	24.59
SEm±	0.16	0.15	0.79	0.64	0.05
CD (P=0.05)	0.44	0.42	2.23	1.82	0.15

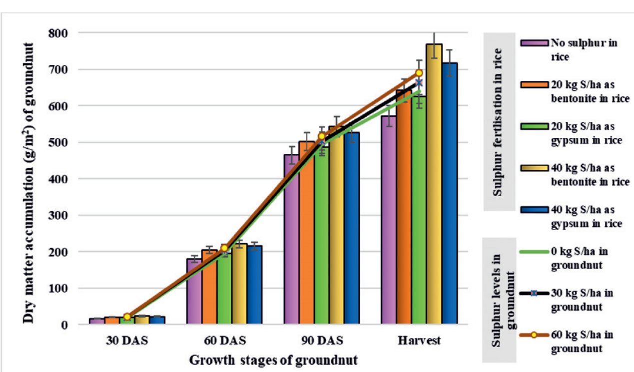
F, Sulphur fertilization in rice; L, Sulphur levels in groundnut

Table 2. Effect of sulphur management on productivity of rice under rice-groundnut cropping system

Treatment	Sulphur levels in groundnut (kg/ha)			
Sulphur fertilization in rice	L_1:0	L_2:30	L_3:60	Mean
Grain yield (t/ha)				
F_1, No sulphur	3.71	3.87	4.04	3.87
F_2, 20 kg S/ha as bentonite	4.11	4.16	4.20	4.15
F_3, 20 kg S/ha as gypsum	4.21	4.64	4.50	4.45
F_4, 40 kg S/ha as bentonite	4.46	4.67	4.85	4.66
F_5, 40 kg S/ha as gypsum	4.75	4.77	4.90	4.81
Mean	4.25	4.42	4.50	4.39
	F	FL	F × L	L × F
SEm±	0.04	0.02	0.10	0.10
CD (P=0.05)	0.13	0.07	0.30	0.27
Straw yield (t/ha)				
F_1, No sulphur	5.65	5.80	5.94	5.80
F_2, 20 kg S/ha as bentonite	6.01	6.07	6.15	6.08
F_3, 20 kg S/ha as gypsum	6.25	6.69	6.57	6.50
F_4, 40 kg S/ha as bentonite	6.62	6.86	7.11	6.86
F_5, 40 kg S/ha as gypsum	6.98	6.96	7.12	7.02
Mean	6.30	6.47	6.58	6.45
	F	L	F × L	L × F
SEm±	0.04	0.03	0.09	0.11
CD (P=0.05)	0.11	0.08	0.27	0.30

F, Sulphur fertilization in rice; L, Sulphur levels in groundnut; F × L, Sulphur fertilization in same or different levels of L; L × F, Sulphur levels in same levels of F

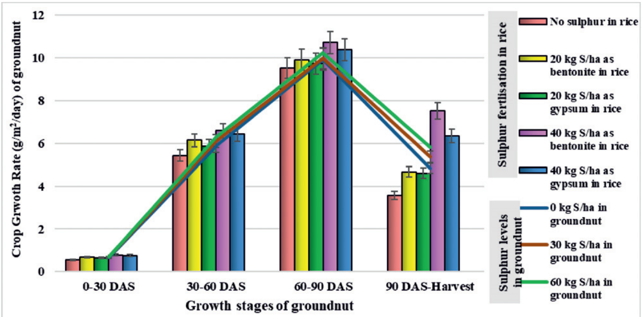
tributed to sufficient residual sulphur in soil for the succeeding groundnut. Ram *et al.* (2017) reported similar residual effects phosphogypsum @ 60 kg S/ha applied to aerobic rice on succeeding wheat. Application of 60 kg sulphur to groundnut produced the maximum dry matter of 21.1, 209.5, 516.3 and 690.7 g/m^2 at 30, 60, 90 DAS and harvest, respectively and proved superior to other levels (Fig. 4). The increase in dry matter could be attributed to



DAT- Days after sowing; S- sulphur; ha- hectare

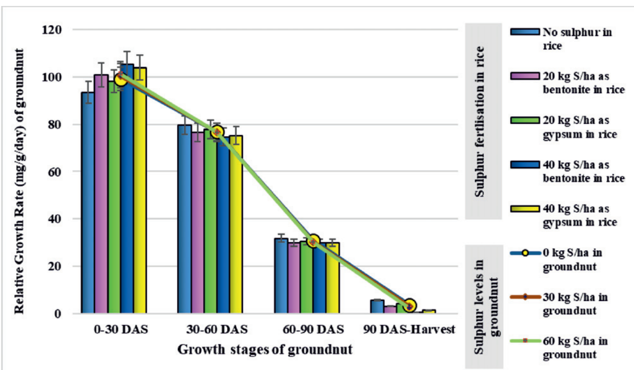
Fig. 4. Effect of sulphur mnagement on dry matter accumulation of groundnut under rice-groundnut cropping system

enhancement in sulphur mediated processes, viz. chlorophyll formation, synthesis of sulphur-containing amino acids and enzyme activation. Dileep *et al.* (2021) also found the maximum dry matter production with the highest level of 40 kg S/ha. Application of 40 kg S/ ha as bentonite in rice recorded the maximum CGR values of 0.79, 6.58, 10.72 and 7.52 g/m^2/day at 0–30, 30–60, 60–90 DAS and 90 DAS- harvest, respectively and proved better than other sulphur fertilisation methods (Fig. 5). As a source of sulphur, bentonite sulphur proved better than gypsum in enhancing CGR values of succeeding groundnut due to its slow releasing nature, partial utilisation by rice and leaving adequate residual sulphur in soil for use by groundnut. Among sulphur levels, application of 60 kg S/ha in groundnut recorded the maximum CGR values of 0.70, 6.28, 10.23 and 6.34 g/m^2/day during 0–30, 30–60, 60–90 DAS and 90 DAS-harvest, respectively (Fig. 5). The gradual decline in RGR with the advancement of crop growth stages is in conformity with findings of Chandrika *et al.* (2015) and Behera *et al.* (2022). Sulphur fertilisation methods in rice exhibited variable trend for RGR in groundnut at different growth stages (Fig. 6). Among sulphur levels, application of 60 kg S/ha in groundnut recorded the maxi-



DAS- Days after sowing; S- sulphur; ha- hectare

Fig. 5. Effect of sulphur management on crop growth rate of groundnut under rice-groundnut cropping system



DAS- Days after sowing; S- sulphur; ha- hectare

Fig. 6. Effect of sulphur management on relative growth rate of groundnut under rice-groundnut cropping system

mum RGR values (101.37, 76.72, 30.08, 2.20 mg/g/day at 0–30, 30–60, 60–90 DAS and 90 DAS-harvest, respectively) and proved superior to other S levels.

Yield attributes

Application of 40 kg S/ha as bentonite sulphur to rice produced the maximum pods/plant (21.2), 100 kernel weight (41.8 g) and kernel/pod (1.9), keeping 40 kg S/ha as gypsum at par (Table 3). These two sulphur fertilisation methods could satisfy S need of rice, while leaving residual S for better growth and yield attributes of groundnut. The maximum sulphur level (60 kg of S/ha to groundnut) recorded higher values of yield-contributing characters *viz.*, pods/plant (20.3), 100 kernel weight (39.4 g) and kernel/pod (1.79) than two lower levels of sulphur. The maximum values of yield attributes with the maximum level of sulphur was due to involvement of sulphur in promoting meristematic tissue, enlarging photosynthetic surface, enhancing chlorophyll content and increasing dry matter accumulation. Yadav *et al.* (2018) reported enhanced yield attributes of groundnut with application of 60 kg of S/ha. Dileep *et al.* (2021) reported higher values of yield attributes with 40 kg S/ha than 20 and 30 kg S/ha in groundnut.

Productivity

Application of 40 kg S/ha as bentonite sulphur to rice recorded the maximum pod (2.07 t/ha) and proved significantly superior to the other sulphur fertilisation methods (Table 4). Sulphur fertilisation methods, viz. 40 kg S/ha as bentonite sulphur and 40 kg S/ha as gypsum to rice increased pod yield of groundnut by 18.2 and 15.4%, respectively, over no sulphur application (control). Fertilisation with 40 kg S/ha as bentonite sulphur produced the maximum haulm (3.87 t/ha), keeping 40 kg S/ha as gypsum at par. Earlier, Samant *et al*. (2023) reported existence of carry over effect of nutrients applied in rice on succeeding

Table 3. Effect of sulphur management on yield attributes of groundnut under rice-groundnut cropping system

Treatment	Pods/Plant	100 kernel weight (g)	kernels/pod
Sulphur fertilization in rice			
F_1, No sulphur	16.6	34.6	1.46
F_2, 20 kg S/ha as bentonite	19.5	38.6	1.60
F_3, 20 kg S/ha as gypsum	18.6	37.4	1.63
F_4, 40 kg S/ha as bentonite	21.2	41.8	1.90
F_5, 40 kg S/ha as gypsum	20.5	40.1	1.89
SEm±	0.41	0.55	0.024
CD (P=0.05)	1.19	1.60	0.069
Sulphur levels (kg S /ha) in groundnut			
L_1, 0	17.9	37.4	1.58
L_2, 30	19.6	38.8	1.72
L_3, 60	20.3	39.4	1.79
SEm±	0.19	0.14	0.011
CD (P=0.05)	0.55	0.39	0.030

F, Sulphur fertilization in rice; L, sulphur levels in groundnut

Table 4. Effect of sulphur management on productivity of groundnut under rice-groundnut cropping system

Treatment	Sulphur Levels in groundnut (kg/ha)			
Sulphur fertilization in rice	L_1:0	L_2:30	L_3:60	Mean
Pod yield (t/ha)				
F_1, No sulphur	1.56	1.79	1.89	1.75
F_2, 20 kg S/ha as bentonite	1.70	1.89	1.98	1.86
F_3, 20 kg S/ha as gypsum	1.72	1.89	1.98	1.86
F_4, 40 kg S/ha as bentonite	1.85	2.14	2.22	2.07
F_5, 40 kg S/ha as gypsum	1.84	2.06	2.17	2.02
Mean	1.73	1.95	2.05	1.91
	F	L	F × L	L × F
SEm±	0.012	0.005	0.026	0.018
CD (P=0.05)	0.035	0.013	0.076	0.052
Haulm yield (t/ha)				
F_1, No sulphur	3.20	3.45	3.49	3.38
F_2, 20 kg S/ha as bentonite	3.48	3.56	3.65	3.56
F_3, 20 kg S/ha as gypsum	3.59	3.63	3.65	3.62
F_4, 40 kg S/ha as bentonite	3.66	3.92	4.04	3.87
F_5, 40 kg S/ha as gypsum	3.62	3.85	3.97	3.82
Mean	3.51	3.68	3.76	3.65
	F	L	F × L	L × F
SEm±	0.031	0.010	0.066	0.039
CD (P=0.05)	0.090	0.029	0.191	0.111

F, Sulphur fertilization in rice; L, sulphur levels in groundnut; F × L, sulphur fertilization in same or different levels of L, L × F, sulphur levels in same levels of F

groundnut. Application of 60 kg of S/ha to groundnut produced the maximum pod (2.05 t/ha) and haulm (3.76 t/ha) and proved significantly superior to 0 and 30 kg S/ha (Table 4). Pancholi *et al.* (2017) reported the maximum yield of groundnut with 60 kg S/ha. Patel *et al*. (2018) reported higher values of yield attributes and yield in summer groundnut with application of 40kg S/ha. Residual effects of 40 kg S/ha as bentonite sulphur or gypsum and direct effects of 60 kg S/ha were realised as enhanced pod yield of groundnut in S-deficient soil. The interaction effects of sulphur fertilization in rice and sulphur levels in groundnut were found to be significant on pod and haulm yield of groundnut. Among the treatment combinations, the application of 40 kg S/ha as bentonite in rice and 60 kg S/ha to groundnut (F_4L_3) recorded the maximum pod yield (2.22 t/ha) and haulm yield (4.04 t/ha), keeping 40 kg S/ha as gypsum in rice and 60 kg S/ha to groundnut (F_5L_3) at par (Table 4).

System productivity

Application of 40 kg S/ha as bentonite and 40 kg S/ha as gypsum recorded the equal system REY of 10.59 t/ha, registering 19.3, 11.7 and 8.2% increase over no sulphur, 20 kg S/ha as bentonite and 20 kg S/ha as gypsum, respectively (Table 5). Among S levels applied to groundnut, 60 kg S/ ha (10.36 t/ha) recorded the maximum system REY and proved significantly superior to 30 kg S/ha and no sulphur application. The highest S level (60 kg S/ha) in groundnut increased system REY by 12.4 % over no sulphur (control). The interaction effects of sulphur fertilization in rice and sulphur levels in groundnut were found significant on system REY. Combined application of 40 kg S/ha as bentonite in rice and 60 kg S/ha in groundnut (F_4L_3) recorded the maximum system REY of 11.21 t/ha, keeping 40 kg S/ha as gypsum to rice along with the application of 60 kg S/ha in groundnut (F_5L_3) at par. The maximum REY with 40 kg S/ha as bentonite or gypsum in rice and 60 kg S/ha in groundnut (F_4L_3 and F_5L_3) could be attributed to direct effect of applied sulphur on yield of component crops in the system, residual effect of sulphur in succeeding crop and adequate availability of sulphur for growth and development of both the crops leading to higher yield of component crop in the system. Rathore *et al.* (2022) reported similar increase in system yield due to sulphur fertilisation in pearl millet–mustard cropping system. Sharma *et al.* (2024) also cited the same kind of results.

Table 5. Effect of sulphur management on system productivity of rice-groundnut cropping system

Treatment	Sulphur levels in groundnut (kg/ha)			
Sulphur fertilization in rice	L_1:0	L_2:30	L_3:60	Mean
F_1, No sulphur	8.18	8.99	9.46	8.88
F_2, 20 kg S/ha as bentonite	8.99	9.57	9.87	9.48
F_3, 20 kg S/ha as gypsum	9.14	10.05	10.18	9.79
F_4, 40 kg S/ha as bentonite	9.76	10.81	11.21	10.59
F_5, 40 kg S/ha as gypsum	10.03	10.67	11.06	10.59
Mean	9.22	10.02	10.36	9.86
	F	L	F × L	L × F
SEm±	0.06	0.03	0.13	0.11
CD (P=0.05)	0.16	0.08	0.37	0.31

F, Sulphur fertilization in rice; L, sulphur levels in groundnut; F × L, sulphur fertilization in same or different levels of L; L × F, sulphur levels in same levels of F

Correlation and Regression Analysis

Grain yield of rice exhibited significant positive correlation with yield attributes *viz,* effective tillers/ hill (0.938**), panicle length (0.917**), filled grains/ panicle (0.977**), spikelets / panicle (0.972**) and test weight (0.928**), indicating these yield attributes as determinants of grain yield in rice. These yield attributes also exhibited positive correlation with each other (Table 6). Grain yield (t/ha) of rice increased linearly with increase in dry matter accumulation (g/m^2), exhibiting functional relationship y = 0.0021x + 1.6877, where y = Grain yield (t/ha) and x= Dry matter accumulation (g/m^2). The linear equation explains about 85.39% variation in grain yield of rice (Fig. 7). Pod yield of groundnut exhibited significant positive correlation with yield attributes *viz.,* pods/ plant (0.891**), 100 kernel weight (0.835**), kernels/pod (0.913**), establishing these yield attributes as determinants of pod yield in groundnut. These yield attributes also exhibited positive correlation with each other (Table 7). Pod yield (t/ha) of groundnut increased linearly with increase in dry matter accumulation (g/m^2) and exhibited functional relationship y= 0.002x + 0.5585, where y = Pod yield (t/ha) and x = Dry matter accumulation (g/m^2). The linear equation explains about 69.28% variation in pod yield of groundnut (Fig. 8)

Thus, it is concluded that application of 40 kg S/ha as bentonite sulphur or gypsum in rice and 60 kg S/ha as bentonite sulphur in groundnut is required to boost crop growth and maximise system productivity.

Table 6. Correlation between yield attributes with grain yield of rice

Particulars	Grain yield (t/ha)	Effective tillers/hill	Panicle length (cm)	Filled grains/ panicle	Spikelets/ panicle	Test weight (g)
Grain yield (t/ha)	1					
Effective tillers/hill	0.938**	1				
Panicle length (cm)	0.917**	0.941**	1			
Filled grains/panicle	0.977**	0.949**	0.949**	1		
Spikelets/panicle	0.972**	0.943**	0.905**	0.982**	1	
Test weight (g)	0.928**	0.967**	0.914**	0.958**	0.956**	1

**Correlation coefficient (r) is significant at the 0.01 level (2 tailed)

Table 7. Correlation between yield attributes with pod yield of groundnut

Particulars	Pod yield (t/ha)	Pods/plant	100- kernel weight (g)	kernels/pod
Pod Yield (t/ha)	1			
Pods/plant	0.891**	1		
100 Kernel weight (g)	0.835**	0.933**	1	
Kernels/pod	0.913**	0.836**	0.883**	1

**Correlation coefficient (r) is significant at the 0.01 level (2 tailed)

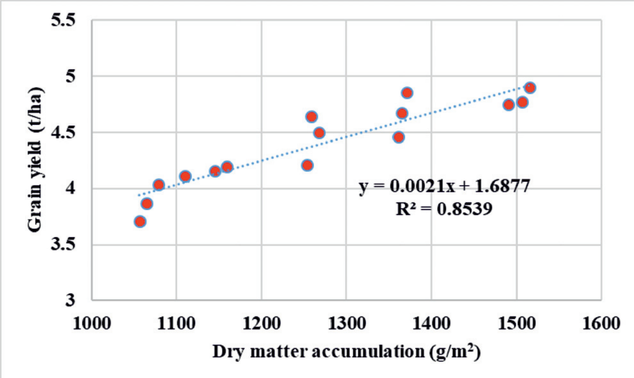


Fig. 7. Regression analysis between grain yield and dry matter accumulation at harvest of rice

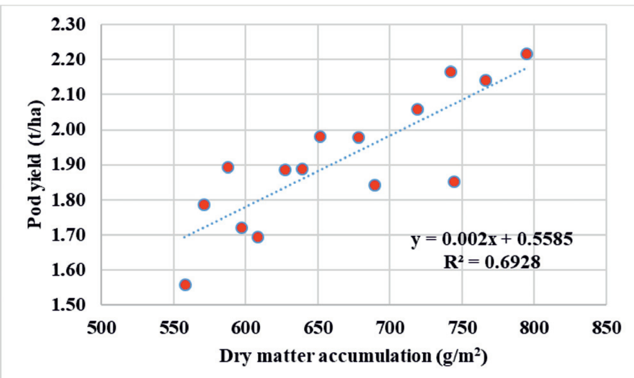


Fig. 8. Regression analysis between pod yield and dry matter accumulation at harvest of groundnut

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