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Management of sulphur for yield augmentation in rice (*Oryza sativa*) under rice fallow system

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ABSTRACT

Sulphur (S) is ranked as 4th most essential nutrient after nitrogen, phosphorous and potassium which plays a vital role in crop production. Its uses have declined in recent years. S-deficiency in soils of Odisha has increased from 36% during 2008–09 to 44% in 2018–19. A field experiment was conducted at farmers' field in Ankurda village, Goindia block of Dhenkanal district, for two years (2018–19 and 2019–20) in order to study the effect of different sources of sulphur in rice (*Oryza sativa* L.) (cv. Swarna Sub 1) under mid-central table land zone of Odisha. The experiment was conducted in RBD with 10 treatments and 3 replications. Four different sources of sulphur (SSP, calcium sulphate, elemental S^0 and navaratna as (20-20-0-13) were used with two methods, viz. basal and top dressing to rice crop during rainy (*kharif*) season. A mixture source was formulated with ($CaSO_4$ + SSP) @1:1 ratio which was applied as basal only. Among the sources of sulphur applied, highest biomass yield was recorded with spilt method of ES which followed the order as: ES^o>mixture source>navaratna>SSP>gypsum. Due to S fertilization, the biomass yield increased by 16% over the control (T_1). Spilt application of sulphur fertilizer exerted a beneficial effect on yield attributing character, higher grain and straw yield, nutrient uptake, sulphur use efficiency and sulphur harvest index, quality parameters and B:C ratio of Swarna Sub-1 in comparison to basal application of fertilizers during rainy (*kharif*) season.

Keywords: Grain quality, Nutrient uptake, Rice, Sulphur use efficiency

Rice (*Oryza sativa* L.) is one amongst the foremost necessary crops of the world grown in tropical and climatic zone regions. As regards to space and production of rice, India ranks second following China holding first position (Nayak *et al.* 2013). Currently, rice pre-occupy 11.40 million ha of land with production of 34.23 million tonnes (Singh *et al.* 2012). Rice being the principal and ancient crop in Odisha, occupied the cultivated space of 61.80 lakhs ha. In India, about 11.7 m/ha remains fallow during winter (*rabi)* season because of various biotic and abiotic stress as well as socio-economic constrains (Ghosh *et al*. 2012), which restricts horizontal growth of rice space (Abdullah *et al*. 2015). Hence, the one avenue left is to extend production of rice by vertical means that is possible through introduction of high yielding varieties and acceptable agronomical management practices. Sulphur (S) is an important plant nutrient that is gaining international attention. Rice producers typically administer high rates of nitrogen, phosphorus, and potassium to the crop. When there is a nutritional imbalance between offtake and input, soil fertility suffers and the incidence of shortages of specific plant nutrients, particularly sulphur and zinc, rises. S exists in soils in both inorganic and organic forms and is cycled between them by mobilisation, mineralization, and immobilisation, as well as oxidation, reduction, and volatilization processes. Sulphur deficiency reduces tiller numbers, plant growth as well as yield of rice (Ghosh *et al.* 2012). Intensive agriculture practices, multiple cropping systems, use of sulphur free fertilizers associated with negligible use of organic manure leads to an alarmic condition. Aiming for a bumper yield, farmers should use fertilizers for boosting the yield as well as the soil health. Therefore, an effort was made to study the effect of different source as well as different methods of sulphur application in *kharif* rice in rice-fallow areas.

MATERIALS AND METHODS

An experiment was conducted in randomised block design (RBD) with 3 replications and 10 treatments such as; T_1, Control (No Sulphur); T_2, Basal application of 30 kg S/ha to rice through Gypsum; T_3, Basal application of 30 kg S/ha to rice through Elemental Sulphur; T_4, Basal application of 30 kg S/ha to rice through Single Super Phosphate (SSP); T_5, Basal application of 30 kg S/ha to rice

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through Navaratna (20-20-0-13); T_6, Basal application of 15 kg S/ha as Gypsum and 15 kg S/ha as SSP @1:1 ratio; T_7, Basal application of 15kg S/ha and top dressing of 15 kg S/ha to rice through Gypsum; T_8, Basal application of 15 kg S/ha and top dressing of 15 kg S/ha to rice through Elemental Sulphur (ES); T_9, Basal application of 15 kg S/ha and top dressing of 15 kg S/ha to rice through SSP; T_{10}, Basal application of 15 kg S/ha and top dressing of 15 kg S/ha to rice through Navaratna (20-20-0-13). Nutrients like N, P_2O_5 and K_2O were applied as per the soil test-based doses through Urea, Diammonium Phosphate (DAP) and Muriate of potassium (MOP). The experiment was carried out for two consecutive years (2018–19 and 2019–20). Composite surface soil samples were collected from different spots of experimental site for soil chemical analysis. The rice variety *Swarna Sub-1* was sown in the experimental plot as per the treatment plans; grain and straw yield were recorded at harvest of rice crop. Different physio-chemical properties of soil sample and plant samples were analysed with standard procedure (Panda 2019). Mature seeds were also analysed for S-containing amino acids, viz. protein, methionine (Horn *et al*. 1946) and cysteine (Gaitnode *et al.* 1947).

Sulphur use efficiency (SUE) and Sulphur harvest index (SHI) were calculated as (Islam *et al*. 2016):

$$\text{Sulphur harvest index (\%)} = \frac{\text{S uptake in grain (kg)}}{\text{Total S uptake (kg)}}$$

$$\text{Sulphur Use efficiency (SUE)} = (Y_t - Y_{Ac}) / S_a$$

Where Y_t, grain yield (kg/ha) of rice in S applied plots; Y_{Ac}, grain yield (kg/ha) in control plot (without Sulphur); S_a, S applied (kg/ha). The analysis of variance (ANOVA) of different variables of different treatments was statistically calculated at P=0.05 level of significance by using DSSTAT software package.

RESULTS AND DISCUSSION

Initial soil characteristics: The texture of the experimental site was silt loam (32.6% sand, 48.1% silt and 19.3% clay). The soil was acidic (*p*H 5.12) in reaction, non-hazardous with electrical conductivity (0.009 dS/m), medium in organic carbon content (5.4 g/kg), medium in available nitrogen (262 kg N/ha), available phosphorus (11.6 kg P/ha), available potassium (224 kg K/ha) and available sulphur (9.2 kg S/ha).

Yield attributing characters: Due to S application, the plant growth characters increased significantly over the control T_1 (Table 1). Irrespective of different sources of S applied, S supplementation increased the plant heights, panicle lengths and effective tillers/hill of rice crop by 56.3, 39 and 35% respectively over the control. The plant heights, panicle lengths and effective tillers/hill varied from 82.7–145.5 cm, 9.6–19.3 cm and 6.6–8.4 respectively, although the lowest of these was recorded with control (T_1). Significantly increased plant growth characters were recorded with the treatment T_8 and T_{10} receiving 30 kg S/ha as ES and Navaratna. However, among the basal method of S application, mixture sources (T_6) maintained the highest value. Among the methods of S application, spilt method recorded a superior growth character over the basal method. Sulphur (S) plays a vital role in formation and biosynthesis of protein, chlorophyll and few amino acids. Increase of such plant growth characters is owing to the positive role of S in plant metabolic activity, which led to the increase photosynthesis rate of the rice plant thereby stimulating the plant height, panicle length and effective tillers/hill of the crop. Results of the current study were in conformity with the findings of Shivay *et al.* (2013) and Panda and Dash (2021).

Biomass yield: The mean pooled grain and straw yield (t/ha) ranged from (4.2–5.2) and (4.6–5.6) respectively (Table 1). Irrespective of sulphur sources, the grain yield increased by 18% over the control (T_1). The yield increase over control (%) was recorded highest with 28.6% (T_8) applied as spilt and lowest with 4.8% (T_5) in basal method of S application. The increase in the yield/biomass over

Table 1 Effect of different sources of sulphur on yield attributes, yield and GS ratio of *kharif* rice (pooled over 2 years)

Treatment	Plant heights (cm)	Panicle length (cm)	Effective tillers/hill (no.)	Grain yield (t/ha)	Increase in yield over control (%)	Straw yield (t/ha)	Total biomass (t/ha)	G:S
T_1	82.7	9.6	6.6	4.2	----	4.6	8.8	0.49
T_2	125.5	15.1	7.7	4.7	11.9	5.0	9.7	0.48
T_3	93.9	17.2	8.2	5.1	21.4	5.4	10.5	0.49
T_4	126.5	14.0	7.6	4.8	14.3	5.1	9.9	0.48
T_5	128.3	13.3	7.3	4.4	4.8	4.9	9.3	0.47
T_6	137.5	18.6	8.4	5.1	21.4	5.5	10.6	0.48
T_7	133.1	15.4	7.7	4.9	16.7	5.2	10.1	0.49
T_8	142.5	19.3	8.4	5.4	28.6	5.6	11	0.49
T_9	131.4	16.5	8.0	5.0	19.0	5.2	10.2	0.49
T_{10}	145.5	16.9	8.1	5.2	23.8	5.5	10.7	0.49
LSD (P=0.05)	6.3	5.14	1.05	1.06		1.70		

Treatment details are given under Materials and Methods.

Table 2 Effect of different sources of sulphur on nutrient uptake, sulphur use efficiency, harvest index and grain quality by *kharif* rice (pooled over 2 years)

Treatment	Nutrient uptake by rice (kg/ha)				SUE	SHI (%)	Grain Quality Parameters (%)		
	N	P	K	S			Protein	Cysteine	Methionine
T_1	78.8	16.7	58.9	21.3		27.7	6.1	0.22	0.31
T_2	81.4	19.0	70.2	23.1	15.3	32.8	6.4	0.34	0.46
T_3	95.0	18.6	90.7	31.6	24.8	36.2	6.5	0.64	0.55
T_4	90.0	25.6	76.6	23.8	21.2	33.0	6.5	0.52	0.48
T_5	109.6	21.4	66.4	24.1	12.7	31.0	6.4	0.71	0.74
T_6	112.4	25.5	83.8	34.0	28.7	34.1	6.6	0.38	0.54
T_7	87.6	23.5	72.8	24.4	26.1	36.7	6.5	0.74	0.56
T_8	102.8	24.0	94.0	36.2	28.0	35.7	6.8	0.88	0.94
T_9	100.9	30.5	79.2	28.4	26.3	32.3	6.7	0.78	0.62
T_{10}	112.2	30.9	69.0	26.4	18.4	36.3	6.8	0.80	0.87
LSD (P=0.05)	2.17	1.14	2.81	1.71			0.24	0.14	0.11

Treatment details are given under Materials and Methods.

control (T_1) reflects that sulphur supplementation has catalysed the growth behaviours of the rice plant (Yoon *et al*. 2012). The highest grain yield was recorded with T_8 of 5.4 t/ha. Being small in particle size, ES has a faster oxidation of SO_4^{2-} by soil micro-organism. The finer is S particle size, greater the surface area and faster the SO_4^{2-} formation. Thus, increase in the S surface area results in increased SO_4^{2-} availability to crops increasing the grain yield as well as straw. Results of the study are corroborated with Havlin *et al.* (2016)

Nutrient Uptake: Increase of sulphur supplementation, have increased the uptake NPK and S by 26, 47, 32 and 31.5% respectively. The total NPK and S uptake (kg/ha) ranged from (78.8–122.4), (16.7–30.9), (58.9–94) and (21.3–36.2) kg/ha respectively (Table 2). Among all the treatments, T_1 received the lowest NPK and S among the nutrients uptake. Among the basal method of application, highest uptake was observed with T_6, due to higher solubility of $CaSO_4$ and slow-release pattern of SSP nutrient. Due to the synergistic effect of S with N (S×N) and phosphorous (S×P) the uptake has significantly increased with S application irrespective of sulphur sources. The highest uptake of S was recorded with T_8 (36.2 kg/ha). ES being highest in S content (90–95%) contributed towards maximum uptake of S in rice plant (Degryse *et al*. 2016, Mishra *et al*. 2020).

Sulphur use efficiency: Sulphur use efficiency (SUE) depends on its uptake, transport, or mobility by the crop from the soil solution pool and the readily available sulphur sources in soil ecosystem (Havlin *et al*. 2016). Results indicated that, SUE of 28.7 kg grain/kg of sulphur applied (Table 2) was recorded with T_6 whereas lowest value of 15.3 kg grain/kg of sulphur applied with T_2. Irrespective of sources of sulphur, SUE was higher due to split application of respective sulphur sources than that of basal application. Among basal application, highest SUE of 28.7 kg grain/kg of sulphur was recorded with T_6 followed by T_3, T_4, T_2 and T_5. Among the spilt application, highest SUE of 28 kg grain per kg of sulphur, was recorded with T_8 which was due to more availability of sulphur during reproductive stages as well as reduction through leaching of sulphate that was formed during oxidation (Havlin *et al*. 2016).

Sulphur harvest index: Maximum sulphur harvest index (SHI) of 36.7% was recorded with T_7whereas lowest value of 27.7% was recorded with T_1 (Table 2). Irrespective of the sources of sulphur, SHI increases by 24%. Among the basal application of different sources of sulphur, the highest SHI of 36.2% was recorded with T_3 followed by T_6 (34.1%), T_4 (33%), T_2 (32.8%), T_5 (31.0%). Spilt application of sulphur was recorded best with T_7 followed by T_{10} (36.3%), T_8 (35.7%) and T_9 (32.3%).

This promoting effect could be related to the ability of gypsum and sulphur to reduce soil *p*H, improve soil structure and increase the availability of nutrients in the soil, while also improving the use efficiency of other essential plant nutrients as well as the harvest index (Havlin *et al*. 2016).

Quality parameter: Grain quality of a crop (Table 2) depends on proper nutrient translocation and its accumulation from source to sink (Havlin *et al*. 2016). It was analyzed that T_8 and T_{10}, the protein content (6.8%) was highest and lowest with (6.1%). Irrespective of sources of sulphur, higher protein content was recorded in split application of sulphur than that of basal application and it followed the decreasing order of T_8= T_{10}>T_9>T_7 which increased by 8% over control due to S supplementation. Data pertaining to cysteine and methionine content ranged from 0.22–0.88% and 0.31–0.94%. Irrespective of source of sulphur, higher cysteine and methionine content was observed in spilt application of sulphur than that of basal application in T_8 @15 kg/ha with ES. Sulphur is an essential nutrient which plays a vital role in the synthesis of amino acids (methionine and cystine), proteins, chlorophyll and certain vitamins. Plants absorb S mainly in the form of

Table 3 Effect of different sources of sulphur on cost of cultivation and B:C ratio in *kharif* rice (pooled over 2 years)

Treatment	Total cost (₹/ha)	Net profit (₹/ha)	B:C ratio
T_1	34345	31913.55	0.93
T_2	35340	56125.74	1.59
T_3	37445	64158.24	1.71
T_4	35495	58132.89	1.64
T_5	34945	56707.47	1.62
T_6	35340	62112.17	1.76
T_7	37445	61377.78	1.64
T_8	35495	63805.53	1.80
T_9	34945	59375.69	1.70
T_{10}	36245	65037.78	1.79

Treatment details are given under Materials and Methods.

inorganic sulphate (SO_4^{2-}) ions through the roots, thus Sulphate (S) must be present in soils in sufficient amount in order to meet crop S requirements. ES showed a faster oxidation due to smaller particle size, they dispersed sulphate ions easily when applied as spilt method in the experiment. (Dash *et al*. 2015)

Economics: Benefit cost (B:C) analysis is an approach in estimating the strength and weakness of the package of practice used in a particular crop. Data pertaining to benefit cost ratio (B:C) are appended at Table 3. Among different treatments, maximum benefit cost ratio (B:C) of 1.80 was recorded with T_8 whereas lowest value of 0.93 was recorded with T_1. The use of elemental sulphur as a source of sulphur nutrient for *kharif* rice crop was economically beneficial to the farmers.

Results of the present study indicated that spilt application of ES @30 kg S/ha was more beneficial with respect to yield attributing characters, grain and straw yield, total nutrient uptake and grain quality as compared to its basal application. Among the different sulphur sources, ES was found to be more cumulative and thus can be recommended to the farmers of the agroclimatic zone to get more yield in a sustained manner.

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