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Research Paper

Effect of sulphur on growth, productivity and economics of aerobic rice (*Oryza sativa*)

ASHA RAM[1], DINESH KUMAR[2], NAIN SINGH[4] AND ANJALI ANAND[3]

Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A field experiment on rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system was conducted during the rainy season (*kharif*) of 2010 and 2011 with 5 treatments in rice (viz. control and 30 and 60 kg S/ha each through gypsum and phosphogypsum) and 3 treatments in wheat (viz. 0, 15 and 30 kg S/ha through elemental sulphur) at New Delhi. Irrespective of the sources, sulphur application had a positive and significant influence on growth parameters, sulphur uptake, sulphur-use efficiency, yield attributes and grain yield of aerobic rice. The sulphur uptake by grain and straw of rice increased with sulphur applied through gypsum or phosphogypsum. The highest agronomic efficiency, crop-recovery efficiency and physiological efficiency was observed with S applied @ 30 kg S/ha through gypsum. Averaged across 2 years, application of sulphur through gypsum @ 30 kg S/ha, gypsum @ 60 kg S/ha, phosphogypsum @ 30 kg S/ha and phosphogypsum @ 60 kg S/ha increased the grain yield of rice by 9.5, 11.2, 8.7 and 10.7% respectively, over the control (no sulphur). However, significant response to sulphur was observed only up to 30 kg S/ha applied through either of the sources. Sulphur application @ 60 kg S/ha gave the highest net returns but statistically not superior to 30 kg S/ha. The highest benefit: cost ratio was recorded with application of sulphur @ 30 kg/ha through gypsum.

***Key words* :** Aerobic rice, Economics, Gypsum, Phosphogypsum, Sulphur sources, Sulphur uptake, Sulphur-use efficiency, Yield

Rice is a staple food for more than half of the world population and generally grown by transplanting seedlings into a puddled soil in Asia. This transplanted rice (TPR) production system is labour-, water-, and energy-intensive and proved less profitable, as these resources are becoming increasingly scarce (Kumar and Ladha, 2011). Efforts are therefore underway to develop water-saving technologies such as system of rice intensification (SRI) and aerobic rice system (ARS). The ARS is a new production system in which rice is grown under non-puddle, non-flooded, and non-saturated soil conditions as other upland crops (Prasad, 2011). The expected yields in ARS are somewhat lower than those obtained under lowland flooded conditions, but double or treble of that obtained under upland conditions. The major gain is saving in water, which may be 50–60% less water required in ARS as compared to TPR. In ARS, soils are kept aerobic almost throughout the rice-growing season (Prasad, 2011).

During the Green Revolution era, India had achieved food security owing to introduction of high-input-responsive varieties of rice and wheat. But, it is observed that rice yields are either decelerating/stagnating/declining in post-Green Revolution era mainly due to imbalance in fertilizer use, soil degradation, type of cropping system practiced, lack of suitable rice genotypes for low moisture adaptability and disease resistance (Prakash, 2010). The removal of nutrients such as N, P, K and S with harvested rice increased markedly with greater yields of new system (Chandel *et al.,* 2003). Furthermore, the continuous use of chemical fertilizers in imbalanced proportion has led to deciency of certain plant nutrients such as sulphur as well as deteriorating soil physical conditions by giving more emphasis to the use of nitrogenous and phosphatic fertilizers.

Sulphur (S) deficiency is widespread now in India. Out of 142 million ha arable land in India, at least 57 million ha, that is, about 40% of total, suffers from various degrees of S deficiency (Tripathi, 2003). The fast decline in available soil S is chiefly due to higher crop removal by high-yielding genotypes; high cropping intensity; poor

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[1]**Corresponding author Email:** ashusirvi84@gmail.com

[1]Scientist, National Research Centre for Agro-Forestry, Jhansi, Uttar Pradesh; [2]Principal Scientist, [4]Technical Officer, Division of Agronomy; [3]Principal Scientist, Division of Plant Physiology

replenishment in soil due to use of S-free fertilizers. Thus, under these situations the application of S-fertilizers becomes imminent to harvest good crop yields of aerobic rice. A host of sulphur fertilizers are available in India, but most common being gypsum due to its lower prices and ease in availability. Phosphogypsum, a byproduct of calcium superphosphate industry, yet another low-priced source of sulphur, is getting attention and market acceptance as S source. As leaching of sulphate is anticipated under aerobic rice, application of slow-acting S carriers can be useful (Nayak *et al.,* 2013). Keeping the above facts in view, the experiment was carried out to study the effect of different sulphur sources and levels on growth, sulphur uptake, sulphur use efficiencies, productivity and economics of aerobic rice grown in aerobic rice–wheat cropping system.

MATERIALS AND METHODS

The field experiment was carried out during the rainy season (*kharif*) of 2010 and 2011 at Indian Agricultural Research Institute, New Delhi, (28°40’ N, 77°12’ E and 228.6 m). The soil was sandy clay loamand had 176 kg/ha available N, 14.6 kg/ha available P, 277 kg/ha available K, 16.5 kg/ha available S and 0.47% organic carbon. The pH of soil was 7.5. The experiment was laid out in randomized block design in rice during *kharif* 2010 with 5 treatments (viz. control and 30 and 60 kg S/ha each through gypsum and phosphogypum) and 3 replications. In the subsequent wheat season, each main plot was split into 3 subplots and 0, 15 and 30 kg S/ha was applied through elemental sulphur.

Main field was irrigated, ploughed and made ready for sowing. Recommended doses of NPK Zn (150, 26.2, 33.2, 5.0 kg/ha respectively) along with sulphur treatments were applied every year. Total P, K, Zn, 1/3 N and S (as per treatment) were broadcast before sowing. The remaining N was top-dressed at tillering and panicle-initiation stages in 2 equal splits. Rice hybrid ‘PRH 10’ was sown at 40 kg/ha in rows, with a row-to-row spacing of 20 cm. The sowing was done on 15 June, 2010 and 9 June, 2011. The individual plot size was 5.5 m × 2.5 m. Rice was grown as per recommended practices and harvested on 6 October, 2010 and 1 October, 2011.

Plant height of the aerobic rice was measured from the base of the plant at ground surface to the tip of the longest leaf. Numbers of tillers were recorded by counting from the sampling unit. Leaf-area was measured by using leaf-area meter (Model LICOR 3000, USA). Leaf-area index (LAI) was computed 30, 60 and 90 days after sowing (DAS) as per Evans (1972). The leaf chlorophyll content was monitored with chlorophyll meter (SPAD-502) at the midpoint of the second fully expanded leaf of 10 marked plants (Lin *et al*., 2010) at 30, 60 and 90 DAS. The S uptake was calculated by multiplying grain and straw yields with corresponding values of their concentrations and expressed in kg/ha. The various sulphur-use efficiencies, viz. agronomic, crop recovery and physiological of sulphur, were computed using the following expressions as suggested by Fageria and Baligar (2003) and Dobermann (2005):

Agronomic efficiency of applied S (AE, kg grain increase/kg S applied) = $(Y_t–Y_0)/A_t$

wherein, Y_t, yield under test treatment (kg/ha); Y_0, yield under control (kg/ha); A_t, units of nutrient (S) applied in the test treatment (kg/ha)

Crop recovery efficiency (CRE, %) of applied S = $[(S_t–S_0)/S_a] \times 100$

wherein, S_t, amount of nutrient uptake (S) from test treatment plot (kg/ha); $S_{0,}$ amount of nutrient uptake (S) from the control plot (kg/ha); S_a, amount of nutrient (S) added (kg/ha)

Physiological efficiency (PE, kg DM increase/kg S uptake) of S = $(Y_t–Y_0)/(U_t–U_0)$

wherein, Y_t, yield under test treatment (kg/ha); Y_0, yield under control (kg/ha); U_t, uptake of nutrient (S) in test treatment (kg/ha); U_0, uptake of nutrient (S) in control (kg/ha).

Ten panicles were sampled for measurement of mean panicle length, panicle weight and number of filled grains/panicle. The 1,000-filled grains, taken from sampled panicles and then weighed to compute the 1,000-grain weight. After harvesting, threshing, cleaning and drying, the grain yield was recorded at 14% moisture. Straw yield was obtained by subtracting grain yield from the total biomass yield. Net returns were computed on the basis of grain and straw yield, their prevailing market prices and cost of cultivation. Benefit: cost ratio was computed by dividing the net returns by total cost of cultivation. The data were statistically analysed using the *F*-test as per the procedure given by Gomez and Gomez (1984). CD values at P=0.05 were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Growth

Sulphur application at different levels through gypsum and phosphogypsum significantly influenced the growth parameters, viz. plant height, number of tillers, dry-matter accumulation, leaf-area index, and chlorophyll content (Table 1). Plant height of rice increased slowly in the beginning and then increased quadratically during subsequent growth phases. Application of sulphur significantly increased the plant height up to 30 kg S/ha at 60 days and up to 60 kg S/ha at harvesting. The elemental sulphur applied to wheat did not show any significant residual effects on plant height of succeeding rice.Increase in plant height might be owing to the positive role of S in plant metabolic activity, which may have led to the increased photosynthesis and thereby plant height. These results clearly indicated that sulphur has a definite positive impact on the plant height. The results confirm findings of Singh *et al*. (1993), Chandel *et al*. (2002) and Samaraweera (2009). Sulphur application increased the tillers/m^2 significantly over the control (Table 1). Tillering is the product of expanding auxiliary buds and closely associated with the nutritional conditions of the mother culm during its early growth period, which gets improved by the application of sulphur (Chandel *et al*., 2002; Dewal and Pareek, 2004; Samaraweera, 2009). However, there was a non-significant difference in tiller number/m^2 with 30 and 60 kg S/ha, applied through either of the sources. Dry-matter accumulation at 60 days and at harvesting increased significantly with application of sulphur. It is quite obvious that the continued and balanced supply of nutrients right from early stage of growth resulted in vigorous plant growth, higher leaf area and number of tillers, so eventually resulted in increased dry-matter accumulation (Shukla and Warsi, 2000; Chandel *et al*., 2003, Pooniya and Shivay, 2011).

Application of sulphur at 60 kg S/ha through either of the sources resulted in significantly higher chlorophyll content over the control (no-sulphur). But all the treatments were comparable (Table 1). The elemental sulphur applied to wheat did not show any significant residual effect on chlorophyll content of rice. Leaf-area index (LAI) at 60 and 90 days increased significantly owing to S application (Fig. 1). Though the highest LAI at 60 and 90 days was observed with 60 kg S/ha applied through gypsum, remained comparable with other sulphur treatments. The increase in leaf-area index with increasing sulphur levels may have occurred due to adequate and balanced nutrient supply resulting in better utilization of carbohydrate to form more protoplasm. Adequate sulphur availability helped plants in vigorous leaf growth and their foliage. Accordingly, more leaves with expanded leaf blade were produced resulting in increased leaf-area index (Sachdev *et al*., 1982; Prasad, 1999).

Sulphur uptake and Sulphur use efficiencies

Sulphur application significantly influenced the sulphur uptake by grain and straw of aerobic rice (Table 1). Averaged across 2 years, application of sulphur through gypsum @ 30 kg S/ha, gypsum @ 60 kg S/ha, phosphogypsum @ 30 kg S/haand phosphogypsum @

Table 1. Effect of sulphur sources and levels on growth, sulphur uptake and sulphur-use efficiencies of aerobic rice (pooled data of 2 years)

Treatment	Plant height (cm)		Tillers/m^2		Dry matter accumulation (g/m^2)		Chlorophyll Content (SPAD value)		S uptake by grain (kg/ha)	S uptake by straw (kg/ha)	Agronomic efficiency (kg grain increase/kg S applied)	Crop recovery efficiency (%)	Physiological efficiency (kg DM increase/kg S uptake)
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	90 DAS					
Direct effect													
Control	54.6	98.3	365	286	223	1247	33.1	39.1	4.76	6.54	-	-	-
G@S$_{30}$	58.6	105.5	413	319	251	1355	34.9	40.9	5.93	8.29	14.5	11.0	416
G@S$_{60}$	60.0	107.9	426	329	262	1404	35.7	41.4	6.45	8.70	8.4	7.1	363
PG@S$_{30}$	58.5	104.8	411	316	244	1347	34.6	40.6	6.04	8.01	13.2	10.5	397
PG@S$_{60}$	59.6	106.6	425	325	258	1393	35.6	41.2	6.37	8.66	8.1	6.9	369
SEm±	0.7	0.8	12	7	4	19	0.6	0.4	0.15	0.26	-	-	-
CD (P=0.05)	2.2	2.4	37	20	11	62	2.0	1.4	0.49	0.85	-	-	-
Residual effect													
S$_0$	57.8	103.6	412	315	245	1349	35.0	40.0	5.77	8.14	-	-	-
S$_{15}$	58.8	105.3	415	321	249	1356	35.2	40.7	5.98	8.44	-	-	-
S$_{30}$	59.8	106.8	419	324	254	1367	35.6	40.8	6.15	8.80	-	-	-
SEm±	0.6	1.2	10	8	3	11	0.5	0.6	0.12	0.22	-	-	-
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-

DAS, Days after sowing; DM, dry matter; G, gypsum; PG, phosphogypsum; NS, not significant; S$_{0, 15, 30, 60}$, sulphur @ 0, 15, 30 and 60 kg/ha

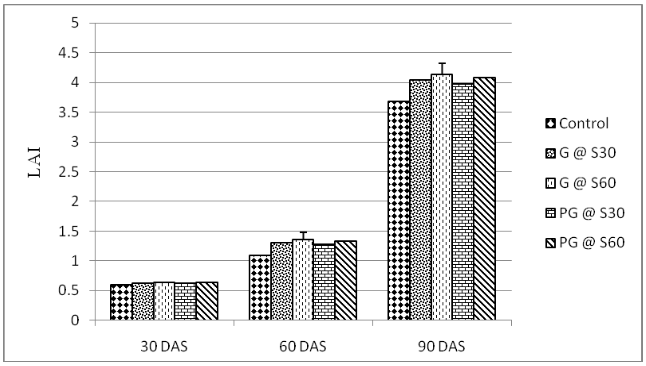

Fig. 1. Effect of sources and levels of sulphur on leaf-area index (LAI) in aerobic rice (pooled data of 2 years)

60 kg S/ha increased the total S uptake of rice by 25.7, 34.1, 24.3 and 32.7% respectively, over the control (no sulphur). But significant response was observed only up to 30 kg S/ha. The increased sulphur uptake by rice might be due to the increased availability of sulphur in soil with successive increment in sulphur levels (Gupta and Jain, 2008; Jena and Kabi, 2012; Crusciol *et al.,* 2012). Another reason of increase in S uptake with S application could be ascribed to increase in grain and straw yield of rice. The agronomic efficiency in other words, the quantity of grain produced for 1 kg S applied ranged from 8.1 kg to 14.5 kg (Table 1). A highest value of agronomic efficiency (14.5 kg grain increase/kg S applied), crop-recovery efficiency (11.0%) and physiological efficiency (416 kg DM increase/kg S uptake) were recorded with 30 kg S/ha, applied through gypsum. This might be owing to small value of the denominator, viz. 30, so values of these efficiencies will be high as compared to 60 kg S/ha. The gypsum releases sulphur at higher rate than phosphogypsum in soil, so sulphur uptake and S use efficiencies were observed higher with gypsum at the same level of sulphur application. The agronomic efficiency, crop-recovery efficiency and physiological efficiency were decreased with increased level of sulphur application up to 60 kg S/ha (Savithri *et al.,* 1999).

Yield attributes

Application of sulphur had also a significant effect on different yield attributes of aerobic rice (Table 2). Effective tillers/m^2 were increased significantly up to 30 kg S/ha, irrespective of the sources. Sulphur application @ 60 kg S/ha through either of the sources significantly increased panicle weight of aerobic rice. Application of the sulphur increased the panicle length, but significant response was observed only up to 30 kg S/ha. However, grains/panicle responded up to 60 kg S/ha applied through either of the sources. The effect of sulphur on 1,000-grain weight was not significant. Residual effects of elemental sulphur applied to preceding wheat were non-significant on different yield attributes of succeeding aerobic rice. As S application enhanced the total tillers/m^2, the number of effective tillers also increased. Enhanced shoot growth and dry-matter accumulation with S application might have increased the values of yield-attributing characters, *viz.* effective tillers/m^2, panicle length and grains/panicle and panicle weight, *etc.* Chandel *et al.* (2002) reported that increasing sulphur levels, applied as single superphosphate, in rice significantly improved yield and yield attributes, such as panicle length, grains/panicle and test weight upto 30 kg S/ha. Our results confirm the findings

Table 2. Effect of sources and levels of sulphur on yield attributes, yields and economics of aerobic rice (Pooled data of two years)

Treatment	Effective tillers/m^2	Panicle weight (g)	Panicle length (cm)	Grains/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	Benefit: cost ratio
Direct effect										
Control	281	2.07	25.1	114	23.9	4.01	7.03	26.9	52.9	1.97
G@S_{30}	300	2.12	26.3	123	25.0	4.40	7.68	27.7	59.8	2.16
G@S_{60}	311	2.19	27.1	130	24.6	4.47	7.74	28.3	60.6	2.14
PG@S_{30}	297	2.11	26.3	122	24.9	4.36	7.62	27.6	59.2	2.14
PG@S_{60}	308	2.19	26.9	128	24.6	4.45	7.73	28.1	60.4	2.15
SEm±	4	0.04	0.3	2	0.5	0.07	0.09	-	1.3	0.04
CD (P=0.05)	14	0.12	0.9	7	NS	0.23	0.28	-	4.4	0.12
Residual effect										
S_0	299	2.14	25.9	122	24.4	4.43	7.73	29.3	63.2	2.16
S_{15}	302	2.16	26.4	123	24.6	4.47	7.8	29.3	64.1	2.19
S_{30}	304	2.18	26.8	125	24.7	4.5	7.83	29.3	64.7	2.21
SEm±	5	0.04	0.6	3	0.4	0.05	0.11	-	1	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	-	NS	NS

G, Gypsum; PG, phosphogypsum; NS, not significant; $S_{0,\ 15,\ 30,\ 60}$, sulphur @ 0, 15, 30 and 60 kg/ha of Sumathy *et. al.* (1999) and Samaraweera (2009).

Grain and straw yields

The grain yield increased significantly with sulphur in rice (Table 2). It rose from 4.01 in the control (no sulphur) to 4.47 t/ha with 60 kg S/ha applied through gypsum. However, response of sulphur was only up to 30 kg S/ha. Averaged across 2 years, application of sulphur through gypsum @ 30 kg S/ha, gypsum @ 60 kg S/ha, phosphogypsum @ 30 kg S/ha and phosphogypsum @ 60 kg S/ha increased the grain yield of rice by 9.5, 11.2, 8.7 and 10.7% respectively, over the control (no sulphur). Application of S to soil increases the availability of SO_4-S in soil (Gupta and Jain, 2008) which might have helped the crop to achieve better growth. As is evident from the Table 2 that S application significantly and positively increased the values of yield attributes, which might have increased the grain yield significantly. The results are in close conformity with findings of Jena *et al.* (2006), Jena and Kabi (2012) and Singh *et al.* (2012). The yield attributes were highly correlated (Table 3) with grain yield. The mean effective tillers/m^2 (r = 0.86**, **significant at 1% level), mean panicle weight (r = 0.83**), mean panicle length (r = 0.80**), and mean number of grains per panicle (r = 0.74*, *significant at 5% level) have shown highly significant and positive correlation with grain yield. The multiple linear regression equation (Fig. 2, Table 4) was also fitted to find out variation in contribution by yield attributes in rice grain yield.

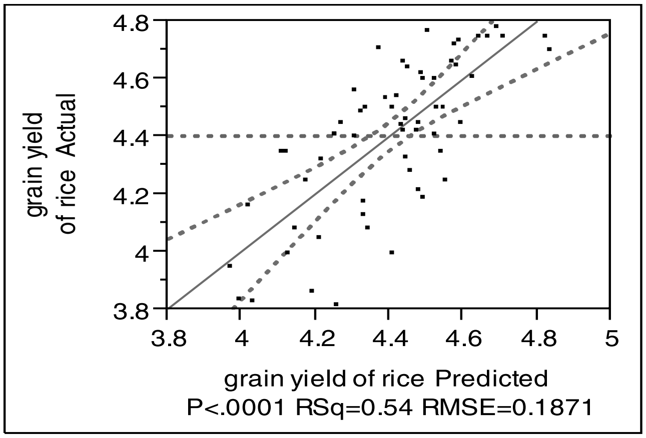

Fig. 2. Rice grain yield predicted through multiple linear regression equation

The straw yield of rice was significantly influenced by application of sulphur (Table 2). Irrespective of the sources, straw yield increased significantly only upto 30 kg S/ha over the control. The increased level of S to 60 kg/ha could not enhance straw yield significantly further. The straw yield varied from 7.03 to 7.74 t/ha. Averaged over 2 years, straw yield increased by 5.1, 6.0, 4.2 and 5.9% under gypsum @ 30 kg S/ha, gypsum @ 60 kg S/ha, phosphogypsum @ 30 kg S/ha and phosphogypsum @ 60 kg S/ha respectively, over the control. The significant improvement in dry-matter production owing to S application might have resulted in higher straw yield of rice. The residual effect of sulphur applied to wheat was not significant on grain and straw yields of rice.

Economics

Economics of aerobic rice was significantly influenced by different sources and levels of sulphur (Table 2). Irre-

Table 3. Correlation between yield attributes and grain yield of aerobic rice

	Grain yield (t/ha)	Effective tillers/m^2	Panicle weight (g)	Panicle length (cm)	Grains/ panicle
Grain yield (t/ha)	1				
Effective tillers/m^2	.858**	1			
Panicle weight (g)	.830**	.884**	1		
Panicle length (cm)	.797**	.977**	.787**	1	
Number of grains/panicle	.743*	.971**	.805**	.988**	1

**Correlation coefficient (r) is significant at the 0.01 level (2-tailed); *Correlation coefficient (r) is significant at the 0.05 level (2-tailed)

Table 4. Parameter estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9293567	0.505794	1.84	0.0716
Number of panicles/m^2	0.007074	0.002444	2.89	0.0054*
Weight of panicle (g)	0.1567435	0.26515	0.59	0.5568
Length of panicle (cm)	0.042721	0.031211	1.37	0.1766
Number of grains/panicle	-0.000923	0.007041	-0.13	0.8961

spective of the sources, the significant improvement in economic parameters was noticed only up to 30 kg S/ha. Averaged over 2 years, gypsum @ 30 kg S/ha, gypsum @ 60 kg S/ha,phosphogypsum @ 30 kg S/ha and phosphogypsum @ 60 kg S/ha gave 13.0, 14.5, 11.7 and 14.1% higher net returns over no sulphur application (control). This might be owing to greater yield increment with sulphur application over the control. Samaraweera (2009) also reported similar economic benefits of sulphur application in rice. The residual effects of elemental sulphur applied to wheat were not found on the economics of rice.

Based on the present findings it is concluded that the sulphur application @ 30 kg/ha applied either through gypsum or phosphogypsum improved growth, sulphur uptake, sulphur-use efficiencies, yield attributes and hence grain yield of aerobic rice. Irrespective of the sources, the increase in S level from 30 to 60 kg/ha could not bring significant improvement in grain yield and net returns of rice. Phosphogypsum was as good as gypsum in improving the yield and economics of rice.

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