Research Articles

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# Relative efficiency of sulphur sources at varying rate in aerobic rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted during 2010-11 and 2011-12 at the research farm of Indian Agricultural Research Institute, New Delhi to study the effect of sulphur fertilization on productivity, economics and nutrient use efficiencies of aerobic rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system.The results revealed that aerobic rice and wheat both responded to sulphur significantly. Sulphur fertilization in aerobic rice through gypsum @ 30 and 60 kg S/ha and phosphogypsum @ 30 and 60 kg S/ha increased the rice equivalent yield of system by 7.8, 10.6, 7.0 and 9.8 %, respectively, over control (no sulphur in rice). The values for per cent increase in rice equivalent yield of systems was 8.4 and 11.6% for 15 and 30 kg S/ha, respectively, when applied to wheat over the control treatment in wheat. Significant response of S applied to rice was found only up to 30 kg S/ha, except 30 kg S/ha applied through phosphogypsum during 2010-11. In wheat, significant response of S was found only up to 15 kg S/ha during second year. During first year of rice-wheat cropping system, economic optimum dose (EOD) of sulphur was 30 kg S/ha through gypsum to rice and 15 kg elemental S/ha to succeeding wheat, while during second year only 30 kg S/ha through either of the sources to rice was found sufficient for both the crops. The apparent sulphur balances and available sulphur in soil were more in higher doses of S application to both the crops. The partial factor productivity, agronomic efficiency and crop recovery of applied S were highest with application of 30 kg S/ha in aerobic rice and 15 kg S/ha in succeeding wheat during both the years of experimentation.

**Key words**: Agronomic efficiency, Apparent sulphur balance, Gypsum, Partial factor productivity, Phosphogypsum, System productivity

Transplanted puddled rice (TPR) is labour-, water-, and energy-intensive and is becoming less profitable as these resources are becoming increasingly scarce specially water (Kumar and Ladha 2011). Aerobic rice system (ARS) is a new production system in which rice (*Oryza sativa* L.) is grown under unpuddled, unflooded, and unsaturated soil conditions as other upland crops (Prasad 2011). RWCS, as a result of several decades of continuous cropping and the contrasting edaphic requirements of the two cereals, have shown evidence of soil nutrient depletion and imbalances, low nutrient use efficiency (Alam *et al.* 2006). This decline in soil fertility and productivity is attributed to the appearance of deficiencies of several plant nutrients including sulphur.

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Sulphur (S) deficiency is widespread now in India. Out of 142 million ha cultivated land in India, at least 57 million ha, that is, about 40% of total, suffers from various degrees of S deficiency (Tripathi 2003). Sulphur deficiency reduces crop yield and quality of the produce (Zuzhang *et al*. 2010). In sulphur deficient soil, the application of high rates of other nutrients (N, P and K) may not result in increased yields, due to imbalances in the N/S and P/S ratios in the plants (Crusciol *et al.* 2006). In addition, an adequate and balanced supply of nutrients favours the proper development of crops, with a positive impact on the yield (Fageria *et al*. 2011). The application of sulphur increases growth and yields in rice (Singh *et al.* 2012a, Jena and Kabi 2012) and in wheat crop (Ercoli *et al*. 2011, Palsaniya and Ahlawat 2009).

A host of sulphur fertilizers are available in India, but most common being gypsum due to its cheaper prices and ease in availability. Phosphogypsum (PG), a byproduct of calcium superphosphate industry, yet another cheaper source of sulphur, is getting attention and market acceptance as S source. Furthermore, since last many years research were started on elemental sulphur but there is little experimental information about the agronomic effectiveness of elemental S (ES) on crops.

Keeping the above facts in view, a field experiment was carried out to study the effect of sulphur fertilization through various sources on productivity, economics and nutrient use efficiencies of aerobic rice-wheat (*Triticum aestivum* L.) cropping system.

## MATERIALS AND METHODS

A field experiment was carried out during 2010-11 and 2011-12 at the research farm of Indian Agricultural Research Institute, New Delhi, situated at a latitude of 28°40' N and longitude of 77°12' E and an altitude of 228.6 m above the mean sea level (Arabian Sea). The mean annual rainfall of research farm is 650 mm and more than 80% generally occurs during South-West-monsoon season (July-September) with mean annual evaporation 850 mm. Soil (TypicUstochrept) of the experimental field had sandy clay loam texture, 176 kg/ha alkaline permanganate oxidizable N (Subbiah and Asija 1956), 14.6 kg/ha available P (Olsen *et al.* 1954), 275 kg 1N ammonium acetate exchangeable K (Hanway and Heidel 1952), 16.5 kg available S (Williams and Steinberg 1959) and 0.54% organic carbon (Walkley and Black 1934) at the start of experiment. The pH of soil was 7.5 (1:2.5 soil and water ratio).

The experiment was laid out in a randomized block design for first season aerobic rice and split plot design for succeeding wheat and second cycle of aerobic rice-wheat cropping system. Five treatments comprising of combinations of two S sources, i.e. gypsum and phosphogypsum and three S levels, i.e. 0, 30 and 60 kg S/ha, were taken for aerobic rice. The amount of calcium and other nutrient present in gypsum and phosphogypsum were calculated and ensured that all the treatments were kept equal except sulphur. In succeeding wheat, each main plot was divided into three sub-plots for application of elemental sulphur at three levels, i.e. 0, 15 and 30 kg S/ha and replicated thrice.

A pre-sowing irrigation was applied in the main field. Afterwards, it was ploughed with tractor-drawn disc plough followed by harrowing till the soil reached to tilth conditions and leveling was done with land leveler. The aerobic rice (variety PRH 10) was sown in all the plots on 15 and 9 June during 2010 and 2011, respectively. After harvest of rice, wheat (variety DBW 17) was sown in *rabi* seasons (24 and 15 November) of 2010 and 2011, respectively. Recommended doses of NPKZn in rice and NPK in wheat along with sulphur treatments were applied every year. Rice was sown at a seed rate of 40 kg/ha in rows, 20 cm apart with recommended practices and harvested on 6 October in 2010 and 1 October in 2011. Wheat was sown at a row spacing of 22.5 cm with a seed rate of 100 kg/ha was harvested on 16 April in 2011 and 17 April in 2012.

Since, the grain yield and market price of both rice and wheat crops differ, hence their combined (system) productivity can only be computed by converting the wheat grain yield into rice equivalent yield. Afterwards, the rice equivalent yield of wheat grain is added with rice grain yield to compute the productivity of the system. The rice equivalents of wheat grain yield were computed as:

$$\text{Rice equivalents (t/ha)} = \frac{\text{Grain yield wheat (tonnes/ha)} \times \text{Price of 1 t wheat grain}}{\text{Price of 1 t rice}}$$

Economics of RWCS was computed based on the prevailing market prices during the respective cropping seasons.

Nutrient balance of S was estimated after two cycles of aerobic rice-wheat rotation. The apparent sulphur balance was calculated by taking differences between the inputs (from sulphur fertilizer) and outputs (from uptake by crops). The calculations were made as follows (Liu *et al.* 2003):

Apparent nutrient balance = nutrient uptake by crops– nutrient additions

The estimated values of partial factor productivity (PFP), agronomic efficiency (AE), crop recovery efficiency (CRE) and physiological efficiency (PE) of applied S were computed using the following expressions as suggested by Fageria and Baligar (2003) and Dobermann (2005):

Partial factor productivity of applied S (PFP, kg grain / kg S)

$$= Y_t/S_a$$

Agronomic efficiency of applied S (AE, kg grain increase /kg S applied)

$$= (Y_t - Y_0)/S_a$$

Crop recovery efficiency (CRE, %) of applied S

$$= [(S_{ut} - S_{u0}) / S_a] \times 100$$

Physiological efficiency (PE, kg DM increase /kg S uptake) of S

$$= (Y_t - Y_0) / (S_{ut} - S_{u0})$$

where, $Y_t$ = Yield under test treatment (kg/ha), $Y_0$ = Yield under control (kg/ha), $S_{ut}$ = Amount of nutrient uptake (S) from test treatment plot (kg/ha), $S_{u0}$ = Amount of nutrient uptake (S) from the control plot (kg/ha), $S_a$ = Amount of nutrient (S) applied (kg/ha).

Analysis of variance (ANOVA) was performed with the PROC MIXED procedure of the SAS/STAT software (SAS Institute 1999) to determine the effects of levels and sources of sulphur on productivity, economics and nutrient use efficiency of rice-wheat cropping systems. Least significant difference (LSD) at 0.05 level of probability and P values were used to examine differences among treatment means.

## RESULTS AND DISCUSSION

### *Yield attributes and productivity of rice*

Application of sulphur had a significant effect on different yield attributes of aerobic rice (Table 1). The number of effective tiller/$m^2$was found to be increased significantly up to 30 kg S/ha, irrespective of the sources. Panicle weight of aerobic rice was increased significantly

Table 1 Effect of sources and levels of sulphur on yield attributes and yield of aerobic rice and wheat (Mean of 2 years)

| Treatment | Rice | | | | | Wheat | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Effective tillers/ $m^2$ | Panicle weight (g) | No. of grains/ panicle | Grain yield (tonnes/ ha) | Straw yield (tonnes/ha) | Effective tillers/ $m^2$ | Spike weight (g) | No. of grains/ spike | Grain yield (tonnes/ ha) | Straw yield (tonnes/ha) |
| *S fertilization to rice* | | | | | | | | | | |
| Control | 281 | 2.07 | 114 | 4.01 | 7.03 | 363 | 1.77 | 45.3 | 4.67 | 6.97 |
| G@$S_{30}$ | 300 | 2.12 | 123 | 4.40 | 7.68 | 368 | 1.79 | 46.0 | 4.92 | 7.31 |
| G@$S_{60}$ | 311 | 2.19 | 130 | 4.47 | 7.74 | 377 | 1.83 | 46.3 | 5.12 | 7.64 |
| PG@$S_{30}$ | 297 | 2.11 | 122 | 4.36 | 7.62 | 366 | 1.79 | 46.0 | 4.89 | 7.38 |
| PG@$S_{60}$ | 308 | 2.19 | 128 | 4.45 | 7.73 | 370 | 1.81 | 46.1 | 5.06 | 7.57 |
| SEm± | 4 | 0.04 | 2 | 0.07 | 0.09 | 5 | 0.02 | 0.5 | 0.06 | 0.10 |
| CD (*P*=0.05) | 14 | 0.12 | 7 | 0.23 | 0.28 | NS | NS | NS | 0.20 | 0.30 |
| *S fertilization to wheat* | | | | | | | | | | |
| $S_0$ | 299 | 2.14 | 122 | 4.43 | 7.73 | 359 | 1.76 | 44.7 | 4.62 | 6.91 |
| $S_{15}$ | 302 | 2.16 | 123 | 4.47 | 7.80 | 370 | 1.79 | 46.0 | 5.01 | 7.52 |
| $S_{30}$ | 304 | 2.18 | 125 | 4.5 | 7.83 | 379 | 1.84 | 47.1 | 5.16 | 7.70 |
| SEm± | 5 | 0.04 | 3 | 0.05 | 0.11 | 5 | 0.02 | 0.5 | 0.06 | 0.11 |
| CD (*P*=0.05) | NS | NS | NS | NS | NS | 14 | 0.05 | 1.2 | 0.16 | 0.30 |

G-Gypsum; PG-Phosphogypsum; NS-Not significant; $S_{0,\ 15,\ 30,\ 60}$ –sulphur @ 0, 15, 30 and 60 kg/ha.

by sulphur application @ 60 kg/ha through either of the sources. Likewise number of grain/panicle increased significantly up to 60 kg S/ha applied through gypsum. Enhanced shoot growth and dry matter accumulation due to S application may have increased the values of yield attributing characters, viz. effective tillers/$m^2$, panicle weight and number of grain/panicle.The findings are consistent with studies reporting that application of sulphur increases the yield attributes of rice and wheat (Chandel *et al.* 2002, Sumathy *et al.* 1999, Samaraweera 2009).

The grain yield increased significantly due to application of sulphur in rice (Table 1). It rose from 4.01 tonnes/ha in control (no sulphur) to 4.47 tonnes/ha with 60 kg S/ha applied through gypsum. However, response of S was observed only up to 30 kg S/ha. Application of S to soil increases the availability of $SO_4$-S in soil (Gupta and Jain 2008) which may have helped the crop to achieve better growth. 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.* (2012a). The yield attributes were highly correlated (Table 2) with grain yield. The mean effective tillers/$m^2$ (r = 0.86**, **significant at 1% level), mean panicle weight (r = 0.83**), and mean number of grains/panicle (r = 0.74*, *significant at 5% level) was highly significant and positive correlation with grain yield. Irrespective of the sources, straw yield increased significantly up to 30 kg S/ha over control (Table 1). However, 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 tonnes/ha. The significant improvement in dry matter production due to S application may 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.

Table 2 Correlation matrix of yield attributes and grain yield of aerobic rice

| | Grain yield (tonnes/ ha) | Effective tillers/ $m^2$ | Panicle weight (g) | Panicle length (cm) | Number of grains/ panicle |
|---|---|---|---|---|---|
| Grain yield (t/ha) | 1 | | | | |
| Effective tillers/$m^2$ | .86** | 1 | | | |
| Panicle weight (g) | .83** | .88** | 1 | | |
| Number of grains/ panicle | .74* | .97** | .81** | .99** | 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)

*Yield attributes and productivity of wheat*

The yield attributes, viz. number of effective tiller/$m^2$, spike weight (g) and number of filled grains/spike were increased significantly by application of 30 kg S/ha over the control (Table 1). The increase in yield attributes with S application might be due to a continued and balanced supply of nutrients (Singh *et al*. 2013) and active involvement of sulphur in root and shoot growth (Zhao *et al*. 2008, Fageria and Moreira 2011), exhibited better plant growth which may have consequently translated into higher yield attributes. Several greenhouse and field studies have shown that the effect of S is primarily on the number of grains/spike (Zhao *et al.* 1999, Monaghan *et al.* 1997) and yield attributes (Pandey *et al*. 2014, Jarvan *et al*. 2012).

The application of sulphur, on an average, increased the wheat grain yield by 10%. Though highest yields (grain and straw) were found with 30 kg S/ha, but significant response was observed only up to 15 kg S/ha. Averaged across two years, application of sulphur @ 15 and 30 kg S/ha increased the grain yield of wheat by 8.4 and 11.6 %, respectively, over control (no sulphur). Various other investigations on sulphur nutrition have also shown that the yield of wheat and some of the yield components significantly responded to the application of sulphur fertilizers (Hoel 2011, Singh *et al*. 2014, Pandey *et al.* 2014). Sulphur application increases the uptake of other nutrients like N, P, K (Singh *et al*. 2013, Dhaker *et al*. 2015) and other micronutrients (Zuchi *et al*. 2012) which might have resulted in increased yield (Togay *et al.* 2008).

The significant residual effects of sulphur sources, viz. gypsum and phosphogypsum applied to preceding aerobic rice were also observed on grain and straw yields of wheat. The highest residual effects of sulphur were observed with 60 kg S/ha applied through gypsum. The marked improvement in productivity of wheat with residual S could be ascribed to the enhancement of $SO_4^{-2}$-S content of the soil as sulphur applied to aerobic rice was not fully utilized by the crop leading to residual effect (Kour *et al*. 2014).

*System productivity*

Irrespective of sources and levels of sulphur applied to rice or wheat, the rice equivalent yield (REY) of RWCS increased significantly over the control during both the years. The highest REY (7.48 and 7.92 tonnes/ha) of RWCS was obtained with application of 60 kg S/ha through gypsum in aerobic rice during 2010-11 and 2011-12, respectively (Table 2). Averaged across two years, S fertilization in rice through gypsum @ 30 and 60 kg S/ha and phosphogypsum @ 30 and 60 kg S/ha increased the REY of system by 7.8, 10.6, 7.0 and 9.8%, respectively, over control (no sulphur in rice). Though application of 60 kg S/ha through gypsum in rice gave higher REY than other S treatments, but all the S treatments applied to remained statistically at par with each other, except 30 kg S/ha applied through phosphogypsum during 2010-11.

Similarly in wheat, S application at either of the rates increased the REY significantly over the control. Sulphur applied in wheat @ 30 kg/ha gave highest REY, i.e. 7.39 and 7.84 t/ha, followed by 15 kg S/ha during 2010-11 and 2011-12, respectively. However, during second year, significant response in REY was found only up to 15 kg S/ ha. Averaged across two years, application of sulphur @ 15 and 30 kg S/ha increased the REY of system by 3.7 and 5.2%, respectively, over control (no sulphur). Grain yield of cereal crops is primarily a product of three yield components: the number of effective tillers/m$^2$, the number of grains/panicle/spike and individual grain weight (Bavec *et al.* 2002). Ontogenetically, number of effective tillers is the first yield component to be fixed, and, thus, assumes particular importance. In both the crops, sulphur application resulted in significantly higher number of effective tillers per unit area over the control. Another reason of increased

Table 3 Effect of sources and levels of sulphur on rice equivalent yield (REY), economics, apparent sulphur balance and its availability in aerobic rice-wheat cropping system.

| Treatments | REY of the system (tonnes/ha) | | Gross returns (X 10$^3$ ₹/ha) | | Net returns (X 10$^3$ ₹/ha) | | B: C ratio | | Initial status of available sulphur in soil (kg/ha) | Total sulphur added (kg/ha) | Total sulphur uptake (kg/ha) | Apperant sulphur balance (kg/ha) | Available sulphur at the end of two cropping cycle (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010-11 | 2011-12 | 2010-11 | 2011-12 | 2010-11 | 2011-12 | 2010-11 | 2011-12 | | | | | |
| *S fertilization to rice* | | | | | | | | | | | | | |
| Control | 6.79 | 7.13 | 135.9 | 156.9 | 86.4 | 102.8 | 1.75 | 1.90 | 16.5 | 30 | 61.7 | -31.7 | 15.3 |
| G @ $S_{30}$ | 7.26 | 7.75 | 145.0 | 170.2 | 94.7 | 115.4 | 1.88 | 2.10 | 16.5 | 90 | 72.2 | 17.8 | 16.8 |
| G @ $S_{60}$ | 7.48 | 7.92 | 149.8 | 174.1 | 98.9 | 118.6 | 1.94 | 2.14 | 16.5 | 150 | 78.0 | 72.0 | 18.6 |
| PG @ $S_{30}$ | 7.20 | 7.70 | 143.9 | 169.4 | 93.7 | 114.6 | 1.87 | 2.09 | 16.5 | 90 | 72.3 | 17.7 | 17.8 |
| PG @ $S_{60}$ | 7.42 | 7.87 | 148.5 | 172.9 | 97.8 | 117.6 | 1.93 | 2.13 | 16.5 | 150 | 75.8 | 74.2 | 18.9 |
| SEm± | 0.07 | 0.08 | 1.4 | 1.7 | 1.4 | 1.7 | 0.03 | 0.03 | | | 1.3 | 1.3 | 0.3 |
| CD ($P$=0.05) | 0.24 | 0.25 | 4.6 | 5.6 | 4.6 | 5.6 | 0.09 | 0.10 | | | 4.2 | 4.2 | 1.0 |
| *S fertilization to wheat* | | | | | | | | | | | | | |
| $S_0$ | 7.04 | 7.44 | 140.4 | 163.2 | 92.1 | 110.4 | 1.91 | 2.09 | 16.5 | 72 | 66.1 | 5.9 | 15.8 |
| $S_{15}$ | 7.27 | 7.74 | 145.4 | 170.4 | 95.0 | 115.5 | 1.88 | 2.10 | 16.5 | 102 | 73.0 | 29.0 | 17.8 |
| $S_{30}$ | 7.39 | 7.84 | 148.0 | 172.4 | 95.7 | 115.6 | 1.83 | 2.03 | 16.5 | 132 | 76.9 | 55.1 | 18.8 |
| SEm± | 0.04 | 0.08 | 0.7 | 1.7 | 0.7 | 1.7 | 0.01 | 0.03 | | | 1.6 | 1.6 | 0.3 |
| CD ($P$=0.05) | 0.10 | 0.23 | 2.1 | 5.1 | 2.1 | NS | 0.04 | NS | | | 4.6 | 4.6 | 0.8 |

G-Gypsum; PG-Phosphogypsum; NS-Not significant; $S_{0,\ 15,\ 30,\ 60}$ –Sulphur @ 0, 15, 30 and 60 kg/ha.

system productivity could be the balanced nutrition (Singh *et al.* 2013). Sulphur helps in decrease of soil pH towards neutrality in alkaline soil and thus enhances the availability of other essential nutrients. Various other investigations on sulphur nutrition have shown that the yield of rice and wheat and some of the yield components significantly responded to the application of sulphur fertilizer (Jena and Kabi 2012, Singh *et al.* 2012b, Palsaniya and Ahlawat 2009, Hoel 2011, Pandey *et al.* 2014).

*System economics*

Irrespective of the sources and levels, application of sulphur to rice increased the gross returns of RWCS significantly over the control. The sulphur application in RWCS @ 60 kg/ha through gypsum in aerobic rice gave highest gross returns (₹ 149 800 and ₹ 174 100) followed by 60 kg S/ha applied through phosphogypsum during 2010-11 and 2011-12, respectively. Similarly, sulphur application @ 30 kg/ha in wheat gave highest gross returns (₹ 148 000 and ₹ 172 400) of aerobic rice-wheat cropping system during 2010-11 and 2011-12, respectively. Almost similar trend was obtained in net returns. During second year, all the S treatments applied to rice remained at par, but significantly higher over the control (no sulphur). The effect of S application to wheat on net returns was found non-significant during second year. The increased gross and net returns might be due to the greater yield increment in crops with sulphur application over the control (Palsaniya and Ahlawat 2009).

The highest B: C ratio (1.94 and 2.14) was observed with 60 kg S/ha applied to rice through gypsum during 2010-11 and 2011-12, respectively. But significant response of S was observed only up to 30 kg S/ha. In wheat, highest B: C ratio (1.88 and 2.10) was obtained with 15 kg S/ha, followed by 30 kg S/ha during 2010-11 and 2011-12, respectively. This might be due to higher increment in economic yield of aerobic rice and wheat. Further, in wheat, elemental sulphur @ 30 kg/ha involved higher cost of cultivation against increase in yield. Hence, B: C ratio was higher with 15 kg S/ha during both the years of experimentation. Another reason might be the residual effect of sulphur sources applied to preceding rice on succeeding wheat at higher level (Shivran 1998, Palsaniya and Ahlawat 2009, Kour *et al.* 2014).

*Apparent sulphur balance and its availability*

The initial available sulphur in experimental soil was 16.5 kg/ha. The apparent sulphur balance was negative (-31.7 kg/ha) in control treatment where no sulphur was added to rice, likewise S balance was observed least positive (5.9 kg/ha) when sulphur was omitted in wheat. The apparent S balance was observed significantly higher with 60 kg sulphur added to rice and 30 kg S added to succeeding wheat. Application of sulphur had a significant effect on available S after end of two years rice-wheat rotation (Table 3). Amongst S treatments applied to rice, 60 kg S/ha applied through phosphogypsum showed highest residual effects, followed by 60 kg S/ha applied through gypsum on available S in soil after harvesting wheat of second cycle. Likewise averaged across two years, application of sulphur in wheat @ 15 and 30 kg S/ha increased the availability of S in soil by 12.1 and 18.2 %, respectively, over control (no sulphur). This might be attributed to the fact that only a small fraction of applied S was utilized by the crop and thus, the unutilized fertilizer S in soil led to the increase the sulphur availability (Shivran 1998, Palsaniya and Ahlawat 2009).

*Nutrient use efficiencies*

Data pertaining to partial factor productivity (PFP), agronomic efficiency (AE), crop recovery efficiency (CRE) and physiological efficiency of applied S (Table 4). The highest PFP (311 kg grain /kg S) was observed with application of 30 kg S/ha through gypsum in aerobic rice, followed by same amount of sulphur applied through phsophogypsum (308 kg grain /kg S). In wheat, sulphur fertilization at 15 kg S/ha gave the highest PFP (623 kg grain/kgS) of applied S. Agronomic efficiency followed

Table 4 Effect of sources and levels of sulphur on partial factor productivity, agronomic efficiency, crop recovery efficiency and physiological efficiency of applied sulphur in aerobic rice-wheat cropping system (Mean of 2 years)

| Treatment | Partial factor productivity (kg grain increase/kg S applied) | Agronomic efficiency (kg grain increase/kg S applied) | Crop recovery efficiency (%) | Physiological efficiency (kg grain increase/kg S uptake) |
|---|---|---|---|---|
| *S fertilization to rice* | | | | |
| Control | | | | |
| G @ $S_{30}$ | 311 | 21.1 | 17.5 | 107 |
| G @ $S_{60}$ | 160 | 15.2 | 13.6 | 108 |
| PG @ $S_{30}$ | 308 | 18.9 | 17.7 | 93 |
| PG @ $S_{60}$ | 159 | 13.8 | 11.8 | 115 |
| *S fertilization to wheat* | | | | |
| $S_0$ | | | | |
| $S_{15}$ | 623 | 27.4 | 22.9 | 196 |
| $S_{30}$ | 317 | 19.1 | 18.0 | 160 |

G-Gypsum; PG-Phosphogypsum; NS-Not significant; $S_{0,\ 15,\ 30,\ 60}$ –Sulphur @ 0, 15, 30 and 60 kg/ha.

almost similar trend to partial factor productivity.

The highest crop recovery of sulphur was observed with 30 kg S/ha (17.7%), applied through phosphogypsum in aerobic rice. But, in wheat, highest crop recovery (22.9%) of S was observed with application of 15 kg S/ha. The highest physiological efficiency (115 kg grain increase /kg S uptake) was observed with 60 kg S/ha, applied through phosphogypsum to rice. Furthermore in wheat, 15 kg S/ha resulted in highest physiological efficiency (196 kg grain increase/kg S uptake) of applied S. Partial factor productivity, agronomic efficiency and crop recovery efficiency are decreased with increased level of nutrient application (Savithri *et al.* 1999).

It can be concluded that for sustainable production of RWCS in Indo-Gangetic Plain Region, balance fertilization is essential. For correcting sulphur deficiency, both the sources, viz. gypsum and phosphogypsum can be used in rice crop and elemental sulphur to wheat. For enhancing productivity of RWC system and nutrinent use efficiency of sulphur, 30 kg S/ha through gypsum/phosphogypsum to rice and 15 kg S/ha through elemental sulphur to wheat found most economically optimum.

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