International Research Journal of Agricultural Science and Soil Science (ISSN: 2251-0044) Vol. 2(5) pp. 179-187, May 2012
Available online http://www.interesjournals.org/IRJAS

Full Length Research Paper

Effect of gromor Sulphur Bentonite sulphur Pastilles on Yield and Nutrient uptake by hybrid rice - potato- green gram Cropping System in an Inceptisol

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Accepted 03 April, 2012

A field experiment was conducted in a medium land site (Inceptisol) of Central Research Station, Orissa University of Agriculture and Technology, Bhubaneswar, India during 2006-09 in order to study the effect of gromor bentonite S pastilles and gypsum on yield and nutrient uptake by hybrid rice-potato-green gram cropping system. Application of S significantly increased the grain and straw yield, nutrient uptake by hybrid rice-potato-green gram cropping system. A dose of 60 kg S ha^{-1} through S-bentonite pastilles increased the yield of hybrid rice, potato and green gram over control by 34, 21 and 18 per cent, respectively. Uptake of N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu by hybrid rice-potato-green gram system were increased significantly in S-treated soil. A dose of 60 kg S ha^{-1} was ideal for hybrid rice and 40 kg S ha^{-1} for potato. Among the three sources, gromor bentonite S pastille was found to be best source of S because of high concentration, slow release and minimum leaching loss.

Keywords: S-bentonite, Gypsum, Hybrid rice-potato-green gram cropping system, Inceptisol, leaching loss.

INTRODUCTION

Sulphur is an essential element for plant and animal. Sulphur deficiency can affect both yield and quality of the crops because this element is required for protein synthesis as it is a component of the aminoacids cysteine, cystyne and methionine (Jones *et al.,* 1982; Wrigley *et al.,* 1984). In past, this element received little attention because fertilizers and atmospheric inputs supplied the soil with adequate amounts of S. Now, areas of sulphur deficiency are wide spread because of intensive farming, use of high analysis S free fertilizers. Analysis of more than 60,000 surface soil samples of country revealed that S deficiency in various states varied from 5 to 83 per cent with an overall mean of 4 per cent (*Singh, 2006*). Results of long term fertilizer experiments on maize-wheat sequence in acid soil of Palampur, on soyabean-wheat sequence in Ranchi and on finger millet-maize sequence in Bangalore clearly showed that crop needs regular S application in acid soils (*Nambiar, 1985*).

Sulphur deficiency in soils of Orissa ranges from 7.0 to 98 per cent with mean value of 28 per cent. Out of 30 districts of Orissa state, 16 districts have more than 50 per cent S deficient soil (*Singh, 2006*). Sulphur deficiency is more pronoused in light textured red and lateritic soils but sufficient in coastal saline soils (Mishra *et al.,* 1990). *Sahoo (1997)* reported that there was significant reduction in rice yield due to continuous application of S free fertilizers to 22 cycles of rice-rice cropping sequence in laterite soil of Bhubaneswar. The present investigation was carried out to study the effect of different levels of gromor bentonite S pastille (90 %S) and gypsum (16 %S) on yield and nutrient uptake by hybrid rice-potato-green gram cropping sequence and to evaluate their relative efficiency in the cropping system.

MATERIALS AND METHODS

A field experiment was conducted during 2006-09 at the Central Research Station of Orissa University of

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Agriculture and Technology, Bhubaneswar, on an Haplaquepts having a pH 4.70, organic carbon 5.4 g kg^{-1} and CEC 4.68 c mole (p^+) kg^{-1}. The soil was deficient in SO_4-S (3.51 mg kg^{-1}), but high in DTPA extractable Fe (18.6 mg kg^{-1}) and Zn (1.05 mg kg^{-1}). The experiment was laid out in a randomized block design with three replications. There were 8 treatments consisting of 3 levels of S (20, 40, 60 kg ha^{-1}) each of gromor bentonite S pastille and gypsum along with SSP @ 40 kg S ha^{-1} and one control. The treatment details were as follows; T_1- control, T_2- 20 kg S ha^{-1} as gypsum, T_3- 40 kg S ha^{-1} as gypsum, T_4-60 kg S ha^{-1} as gypsum, T_5-20 kg S ha^{-1} as gromor bentonite S pastille, T_6- 40 kg S ha^{-1} as gromor bentonite S pastille, T_7- 60 kg S ha^{-1} gromor bentonite S pastille, T_8- 40 kg S ha^{-1} as SSP.

During Kharif, hybrid rice (*cv. Rajyalaxmi*) was transplanted in July while potato tubers (*cv. Kufri Jyoti*) were planted as succeeding crop in November. A common fertilizer dose of 150-50-50 and 150-90-120 kg N-P_2O_5-K_2O ha^{-1} for rice and potato, respectively were applied. Full dose of P through DAP was applied at planting for both the crops. Nitrogen as DAP and prilled urea was applied in the ratio of 1:2:1 at transplanting, maximum tillering, panicle initiation stage, respectively for rice and in 1:1 ratio at planting and first earthing up (25 days after planting) for potato. Potassium through MOP was applied in two equal splits for both the crops. Required quantity of S through gypsum (16 % S) and gromor bentonite S pastille (90 % S) was applied to both crops at planting. In T_8, the requirement of S and P was met through SSP.

After harvest of potato, green gram (*cv. Pusabaisakhi*) was sown during first week of March, to study residual effect of applied S to rice and potato (Generally the farmers of Orissa state do not apply any fertilizers to green gram succeeding potato crop and harvest a bumper crop). The crop received six irrigations during its growth period. The irrigation water contains 0.002 mg l^{-1} of SO_4-S. The crop was harvested during 2nd week of May. Crop yields were recorded at full maturity. Plant samples *viz*. grain, straw, tuber, stalk, seed and haulm of all the three crops were collected at harvest and were analyzed for macro, secondary and micronutrients as per the method of *Jackson (1967)*. Total S content in plant and soil extract was estimated by turbidimetric method (*Chesin and Yien, 1951*). Available S in the post harvest soil was extracted with 0.15 per cent $CaCl_2$ and estimated by turbidimetric method. During next two years (2007-2009) the crop variety, fertilizer dose and management practices were kept same with little variation in planting time (5-7 days).

The sulphur use efficiency parameters were calculated as follows,

$$\text{Sulphur use efficiency (SUE)\%} = \frac{[\text{Grain yield (Treatment)}] - [\text{Grain yield (Control)}] \times 100}{\text{S applied kgha}^{-1}}$$

$$\text{Relative Agronomic Efficiency (RAE)\%} = \frac{[\text{Grain yield (Treatment)}] - [\text{Grain yield (Control)}] \times 100}{[\text{Grain yield (Gypsum)}] - [\text{Grain yield (Control)}]}$$

$$\text{Apparent S Recovery (ASR)\%} = \frac{[\text{S uptake (Treatment)}] - [\text{S uptake (Control)}] \times 100}{[\text{S applied kgha}^{-1}]}$$

Post harvest soil samples from 0-15 and 15-30 cm depth were collected at the end of third year to study the vertical distribution of applied S after hybrid rice-potato-green gram cropping system.

RESULTS AND DISCUSSION

Direct Effect of S on crop yield

Rice

Hybrid rice responded significantly to S application. The grain yield in S treatments ranged from 4.8 to 5.8 t ha^{-1} as against 4.3 t ha^{-1} in control. Application of 60 kg S ha^{-1} through gromor bentonite S pastille recorded highest significant grain yield of 5.8 t ha^{-1} (Table 1). Irrespective of sources, yields under 20 and 40 kg S ha^{-1} were at par but significantly different over control (4.3 t ha^{-1}). This indicated that 60 kg S ha^{-1} is the ideal dose for hybrid rice. Per cent response to grain yield of hybrid rice over control was 12.7-13.5, 19.6-21.3, and 18.1-34.1 % with application of 20, 40, and 60 kg S ha^{-1}, respectively. Similar results were obtained by Jena *et al.* (2006) who reported that grain and straw of rice were higher in S-treated plots than those in control. Among the three S-sources used the grain yield of hybrid rice in gypsum and gromor bentonite S pastille treatments ranged from 4.9 to 5.2 and 4.9 to 5.8 t ha^{-1}, respectively indicating that the latter source gave better response as compared to former under rice ecosystem. This might have happened because of low efficiency of gypsum caused due to higher solubility under puddled condition and leached below the rice root zone. Puddling of soil enhanced percolation rate just after transplanting. On the other hand, S from gromor bentonite S pastille is slowly released and available to the plant for longer period. The grain yield in SSP (40 kg S ha^{-1}) treatment (4.8 t ha^{-1}) was at par with 20 kg S ha^{-1} applied either through gypsum or gromor bentonite S pastilles which seems to be inferior to former two sources. *Singh (2000)*, Jena *et al.* (2006) evaluated the performance of gromor bentonite S pastilles in rice-cowpea and rice-groundnut sequence in Alfisol of Bangalore and acid soil of Bhubaneswar, respectively. Among the sources, gromor bentonite S pastilles gave higher yield over gypsum or SSP, but all the sources were statistically at par, so either sources can be applied.

Table 1. Effect of S bentonite pastilles on grain and straw yield of hybrid rice, potato & green gram (Mean for 3 years)

Treatments	Rice			Potato			Green gram	
	Grain yield (t ha^{-1})	Kg grain/Kg S	Straw yield (t ha^{-1})	Tuber yield (t ha^{-1})	Kg grain/Kg S	Haulm (t ha^{-1})	Seed yield (t ha^{-1})	Stalk (t ha^{-1})
T_1	4.3	-	4.7	17.8	-	3.0	0.6	1.6
T_2	4.9	30	5.1	20.1	115	3.4	0.8	2.2
T_3	5.2	23	5.3	21.3	89	3.8	0.8	2.5
T_4	5.1	13	5.2	21.0	53	3.7	1.0	2.7
T_5	4.9	30	5.0	20.1	115	3.1	0.8	2.4
T_6	5.2	23	5.3	21.6	95	3.5	1.0	2.8
T_7	5.8	25	5.8	21.5	62	3.5	1.1	3.1
T_8	4.7	10	5.0	19.3	38	3.4	0.8	2.1
CD (0.05)	**4.82****		**4.18****	**5.24****		**3.54****	**1.12***	**2.69**

The straw yield showed similar trend. It increased significantly with increasing levels of S. Straw yield in control was 47.50 q ha^{-1} and ranged from 5.1 to 5.3 and 5.1 to 5.9 t ha^{-1} in S-treatments. Highest straw yield (5.9 t ha^{-1}) was recorded sin T_7 (60 kg S ha^{-1} through gromor bentonite S pastilles). Per cent response to straw yield of hybrid rice over control (4.8 t ha^{-1}) was 6-24 with application of 20-60 kg S ha^{-1}.

The grain yield response of hybrid rice decreased with increasing S doses. These values ranged from 13 to 30 and 23 to 30 kg grain kg^{-1} S with application of gypsum and gromor bentonite S pastilles, respectively. Among the three sources, gromor bentonite S pastilles gave higher response as compared to gypsum or SSP (Table 1).

Potato

Response of S to potato was higher as compared to hybrid rice. The mean potato tuber yield ranged from 20.1 to 21.6 t ha^{-1} in S-treatments as against 17.8 t ha^{-1} in control. It increased with increasing S level upto 40 kg S ha^{-1} where as at 60 kg S ha^{-1} either the yield level was declined or remained at par with 40 kg S ha^{-1} treatment. Highest significant tuber yield of 21.6 t ha^{-1} was recorded in T_6 (40 kg Sha^{-1} through gromor bentonite S pastille) which was at par with T_3 and T_7. This indicated that 40 kg S ha^{-1} is the ideal S dose for potato.

Among the three sources, gromor bentonite S pastilles recorded higher tuber yield as compared to gypsum or SSP. Sulphur applied through gromor bentonite S pastille or gypsum increased the tuber yield over control by 12.8 to 19.5 and 13.1 to 21.2 per cent, respectively where as, the response to SSP was 8.4 per cent. The haulm yield of potato ranged from 3.1 to 3.8 t ha^{-1} as against 2.3 t ha^{-1} in control. The tuber yield response of potato deceased with increasing S levels. Similar response was observed in case of hybrid rice. The response was 53 to 115 and 62 to 115 kg tuber kg^{-1} S with application of gypsum and gromor bentonite S pastille, respectively. Lowest response of 38 kg kg^{-1} S was recorded in SSP treatment. *Jena (2007)* evaluated the response of gromor bentonite S pastille and gypsum in rice-potato sequence in alluvial soil and found that the potato tuber yield increased with increasing level of S upto 60 kg ha^{-1}. Highest significant yield of 31.1 t ha^{-1} was recorded with 60 kg S ha^{-1} through gromor bentonite S pastille as against 21.6 t ha^{-1} in the present study. The tuber yield response ranged from 187 to 328 and 188 to 381 kg kg^{-1} S in gypsum and gromor bentonite S pastille treatments, respectively which were higher than the present study. The difference in tuber yield and yield response were influenced mostly due to soil type (alluvial) which favours potato cultivation.

Residual effect of S on yield of green gram

The seed yield of green gram in hybrid rice-potato-green gram cropping sequence ranged from 0.7 to 1.1 t ha^{-1} in S treatments as against 0.6 t ha^{-1} in control. Irrespective of the sources, the seed yield was increased over control by 12 to 80 per cent with S application. Highest significant yield of 1.1 t ha^{-1} was recorded at 60 kg S ha^{-1} through gromor bentonite S pastille. Among the three sources, the yield was higher in gromor bentonite S pastille treatments (0.9 to 1.1 t ha^{-1}) as compared to gypsum (0.8-1.0 t ha^{-1}). Application of SSP @ 40 kg S ha^{-1} recorded seed yield of 0.7 t ha^{-1} which was significantly higher over control by 12 per cent, but at par with 20 kg S ha^{-1} through gypsum. This indicated that, residual effect of gromor bentonite S pastille on green gram was higher as compared to gypsum or SSP might be due to its low solubility. From these results, it may be inferred that S applied to the previous crops (rice and potato) exerted a significant influence on the succeeding green gram crop.

Table 2. Effect of different sources and levels of Sulphur on N, P and K uptake (kg ha^{-1}) by hybrid rice, potato and green gram

Treatment	Rice								
	Grain (kg ha^{-1})			Straw (kg ha^{-1})			Total kg ha^{-1}		
	N	P	K	N	P	K	N	P	K
T_1	44.6	8.9	11.1	25.5	4.5	25.0	70.1	13.4	36.1
T_2	51.8	11.4	12.6	29.2	4.5	32.3	81	15.9	44.9
T_3	57.9	12.1	15.1	31.8	8.4	33.7	89.7	20.5	48.8
T_4	57.3	11.4	13.1	32.4	5.6	34.6	89.7	17	47.7
T_5	50.9	10.3	13.7	30.5	4.8	32.3	81.4	15.1	46
T_6	58.2	11.4	13.3	33.9	5.3	35.3	92.1	16.7	48.6
T_7	65.4	12.6	15.4	39.8	5.5	40.6	105.2	18.1	56
T_8	52.1	10.3	11.8	30.5	5.8	30.5	82.6	16.1	42.3
CD (0.05)	**5.8**	**1.9**	**NS**	**3.0**	**NS**	**4.5**			
				Potato					
T_1	39.9	7.3	62.1	53.5	6.6	31.9	93.4	13.9	94
T_2	48.3	8.5	72.2	61.3	7.7	39.0	109.6	16.2	111.2
T_3	51.9	9.7	80.7	68.2	8.7	56.3	120.1	18.4	137
T_4	52.7	9.7	72.8	68.8	9.3	55.8	121.5	19	128.6
T_5	42.8	10.4	78.2	53.8	10.7	43.6	96.6	21.1	121.8
T_6	58.1	10.0	91.9	65.9	9.0	62.5	124	19	154.4
T_7	58.5	10.8	74.2	68.3	11.5	64.2	126.8	22.3	138.4
T_8	50.2	10.4	81.7	68.2	9.1	39.7	118.4	19.5	121.4
CD (0.05)	**NS**	**1.8**	**11.5**	**7.9**	**NS**	**6.9**			
				Green gram					
T_1	13.0	2.1	6.5	16.7	3.0	22.8	29.7	5.1	29.3
T_2	18.7	3.3	10.1	36.9	5.6	33.0	55.6	8.9	43.1
T_3	25.3	3.5	10.6	34.0	5.1	39.9	59.3	8.6	50.5
T_4	23.8	4.4	13.2	57.9	5.5	45.4	81.7	9.9	58.6
T_5	22.3	3.5	10.6	44.4	4.6	37.9	66.7	8.1	48.5
T_6	27.1	4.0	12.3	39.6	5.9	47.6	66.7	9.9	59.9
T_7	33.2	4.6	13.6	48.8	6.3	52.6	82	10.9	66.2
T_8	19.9	2.9	8.5	41.7	4.2	31.5	61.6	7.1	40
CD (0.05)	**3.2**	**0.5**	**1.9**	**4.8**	**0.6**	**4.5**			

These results are in conformity with the findings of *Pandey (1999)*. Per cent response of residual S to green gram yield was higher as compared to rice and potato. The yield response was increased over control by 21-52.6 and 34.9-79.8 per cent in gypsum and gromor bentonite S pastille treatments, respectively. The stover yield of green gram showed similar trend which ranged from 1.6 to 3.1 t ha^{-1}. The stover yield increased with S levels and higher being in gromor bentonite S pastille as compared to gypsum or SSP treatments. Per cent response to stover yield of green gram over control (1.6 t ha^{-1}) was 42-89 per cent with application of 20-60 kg S ha^{-1} to previous hybrid rice and potato crops.

Uptake of N, P and K

Hybrid rice

The interaction between N and S is generally positive and occasionally additive (no interaction). Nitrogen and S increased each other's recovery from the fertilizer source by the crop resulting in higher fertilizer use efficiency.

The increase in N, P, K uptake by hybrid rice was mainly due to increase in yields of rice with S application. Sulphur application increased N, P and K uptake by hybrid rice (Table 2). The N, P and K uptake ranged from 44.6 to 65.3, 8.9 to 12.6 and 11.1 to 15.4 kg ha^{-1} by grain and 25.5 to 39.8, 4.5 to 5.8 and 24.9 to 40.6 kg ha^{-1} by straw, respectively. Total N, P and K uptake by grain and straw ranged from 81-105.2, 15.1-20.5 and 44.9-56 kg ha^{-1}, respectively. Nitrogen uptake by grain and straw were significantly different over control where as P and K uptakes were non-significant. Several workers have reported that the P x S interaction is synergistic at low-medium levels of P and antagonistic at higher level. The uptake of P by hybrid rice was increased from 13.4 (control) to 20.5 kg ha^{-1} at 40 kg S ha^{-1} (gypsum). When the S dose was increased to 60 kg ha^{-1} (gypsum), the P uptake was decreased to 17 kg ha^{-1}. On the other hand,

when the S was applied through gromor bentonite S pastille, the P uptake was increased significantly up to 60 kg S ha^{-1}. Potassium uptake by grain was non-significant but significant response to K uptake by straw was recorded at 60 kg S ha^{-1} when S was applied through gromor bentonite S pastille. Highest N, P and K uptake was recorded in T_7 (gromor bentonite S pastilles @ 60 kg S ha^{-1}) followed by T_6. Per cent response to N, P, K uptake by hybrid rice over control was 50, 35, 55 per cent, respectively with 60 kg S ha^{-1} (gromor bentonite S pastilles). Similar observations were reported by Dwivedi *et al*. (2002) for maize crop. Sulphur application at moderate level (30 kg S ha^{-1}) helped for better root development and have beneficial effect on P uptake. However, the uptake of P decreased at higher level of S (45 kg S ha^{-1}) which might be due to depressive effect of S (*Singh and Karwasra, 1987*). The results of present study corroborated with findings of *Singh and Karwasra, (1987*) in which P uptake by grain and straw was highest at 40 kg S ha^{-1} and decreased when S dose raised from 40 to 60 kg S ha^{-1} (gypsum).

Potato

Nitrogen, P and K uptake by potato was higher than hybrid rice. Uptake of N, P and K by potato tuber and stover increased with levels of S which ranged from 39.9 to 58.5, 7.3 to 10.8 and 62.1 to 91.9 kg ha^{-1} by tuber and 53.5 to 68.8, 6.6 to 11.5 and 31.9 to 64.2 kg ha^{-1} by stover, respectively (Table 2). Removal of N by stover was higher than tuber where as K uptake was reverse. Total N, P and K uptake by potato tuber and stover ranged from 96.6-126.8, 68.2-22.3 and 111.2-154.4 kg ha^{-1}, respectively. Per cent response to total N, P and K uptake by potato over control was 36, 60 and 47 per cent, respectively with application of 60 kg S ha^{-1} (gromor bentonite S pastilles). Among the three sources, gromor bentonite S pastille recorded higher N, P and K uptake than either gypsum or SSP might be due to its slow solubility and less leaching loss as experienced in rice-potato cropping sequence in alluvial soil *(Jena 2006)*.

Green gram (Residual)

Cumulative application of S to hybrid rice and potato had beneficial effect on succeeding green gram crop. Nitrogen, P and K uptake by green gram seed and stalk in control were 29.7, 5.1 and 29.3 kg ha^{-1}, respectively (Table 2). The N, P and K uptake was increased to 82, 10.9 and 66.2 kg ha^{-1}, respectively at 60 kg S ha^{-1} (gromor bentonite S pastilles). Per cent response to N, P and K uptake by green gram over control was 176, 114 and 126 per cent, respectively with application of 60 kg S ha^{-1} each to hybrid rice and potato. This indicated that cumulative residual effect of S on green gram was higher than the direct effect on hybrid rice and potato. These results are in conformity with the findings of *Pandey (1999)*.

Uptake of Ca, Mg and S

Hybrid Rice

Sulphur uptake by hybrid rice grain, straw and their total uptake in control was 9.5, 10.8 and 20.3 kg ha^{-1}, respectively. These values increased significantly up to 40 kg S ha^{-1} application and thereafter it declined at 60 kg S ha^{-1}. Uptake of S by hybrid rice grain was significantly higher over control where as it was non-significant for straw (Table 3).

Calcium uptake by grain, straw and grain + straw was 18.4, 13.2 and 31.6 kg ha^{-1}, respectively in control. The calcium uptake increased significantly from 31.6 kg ha^{-1} (control) to 56.1 kg ha^{-1} at 60 kg S ha^{-1} might be due to addition of extra dose of calcium to soil through different S sources. Per cent response to Ca uptake by hybrid rice over control (31.6 kg ha^{-1}) was 78 per cent at 60 kg S ha^{-1} (gromor bentonite S pastilles).

Magnesium uptake by hybrid rice (grain + straw) ranged from 15.9 (control) to 21.1 kg ha^{-1} at 60 kg S ha^{-1} (gromor bentonite S pastilles). Uptake of Mg by grain and straw at 40 kg S ha^{-1} was significantly higher over 20 and 60 kg S ha^{-1} levels. Per cent response to Mg uptake by hybrid rice over control was 33% at 60 kg S ha^{-1} (gromor bentonite S pastilles).

Potato

Uptake of Ca, Mg and S in control was 14.9, 6.3 and 8.1 kg ha^{-1} by tuber and 5.9, 7.4 and 7.1 kg ha^{-1} by stover, respectively. With application of 60 kg S ha^{-1} uptake of Ca, Mg and S were increased significantly over control by 49, 18 and 39 per cent. Further the data revealed that irrespective of levels, per cent uptake of Ca, Mg and S by potato were higher with gromor bentonite S pastille followed by gypsum and SSP (Table 3).

Green gram (Residual)

Calcium, Mg and S uptake by seed, stalk and their total uptake by green gram increased significantly with increasing levels of S. Total uptake of Ca, Mg and S by seed and stalk were 33.4, 9.7 and 17 kg ha^{-1}, respectively with 60 kg S ha^{-1} as against 13.3, 5.1 and 6.7 kg ha^{-1}, respectively in control. Residual effect of gromor bentonite S pastille was higher than gypsum or SSP might be due to higher efficiency of former source (Table 3).

Table 3. Effect of different sources and levels of Sulphur on Ca, Mg and S uptake (kg ha^{-1}) by hybrid rice, potato and green gram

Treatment	Rice						Total (kg ha^{-1})		
	Grain (kg ha^{-1})			Straw (kg ha^{-1})					
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
T_1	18.4	7.3	9.5	13.2	8.6	10.8	31.6	15.9	20.3
T_2	24.8	8.5	11.3	17.5	10.0	10.4	42.3	18.5	21.7
T_3	25.8	10.0	12.7	20.1	10.0	14.1	45.9	20	26.8
T_4	30.5	8.6	11.6	19.2	9.7	10.8	49.7	18.3	22.4
T_5	28.5	8.1	10.9	15.3	9.6	14.9	43.8	17.7	25.8
T_6	29.8	8.7	11.9	19.6	10.2	17.8	49.4	18.9	29.7
T_7	33.9	10.1	14.3	22.2	11.0	18.5	56.1	21.1	32.8
T_8	26.5	7.9	10.9	16.2	9.3	15.8	42.7	17.2	26.7
CD (0.05)	**4.3**	**1.4**	**2.0**	**3.2**	**1.1**	**NS**			
				Potato					
T_1	14.9	6.3	8.1	5.9	7.4	7.1	20.8	13.7	15.2
T_2	18.1	7.2	10.4	7.3	8.7	9.8	25.4	15.9	20.2
T_3	20.6	7.0	11.3	8.6	9.8	9.4	29.2	16.8	20.7
T_4	20.6	7.0	9.4	9.0	9.5	11.3	29.6	16.5	20.7
T_5	17.7	7.0	11.3	7.1	7.9	7.7	24.8	14.9	19
T_6	21.0	8.0	13.3	8.7	9.1	9.5	29.7	17.1	22.8
T_7	21.6	7.1	8.9	9.3	9.1	12.3	30.9	16.2	21.2
T_8	17.4	7.0	10.6	7.5	8.9	7.9	24.9	15.9	18.5
CD (0.05)	**0.9**	**0.6**	**NS**	**1.3**	**1.1**	**1.7**			
				Green gram					
T_1	6.4	1.1	1.4	6.9	4.0	5.3	13.3	5.1	6.7
T_2	9.2	1.4	1.5	9.8	5.4	6.8	19	6.8	8.3
T_3	10.5	1.6	2.6	11.7	6.2	9.9	22.2	7.8	12.5
T_4	12.2	1.8	3.1	13.9	6.6	11.0	26.1	8.4	14.1
T_5	11.0	1.6	2.4	11.3	5.8	8.3	22.3	7.4	10.7
T_6	12.9	1.8	2.8	15.0	6.9	11.3	27.9	8.7	14.1
T_7	15.7	2.2	3.9	17.7	7.5	13.1	33.4	9.7	17
T_8	8.2	1.4	1.9	10.2	5.1	7.6	18.4	6.5	9.5
CD (0.05)	**1.5**	**0.2**	**0.4**	**1.9**	**0.7**	**1.1**			

Uptake of Fe, Mn, Zn and Cu

Hybrid rice

Sulphur application increased Fe, Mn, Zn and Cu uptake by hybrid rice from 580 to 880, 766 to 986, 175 to 270 and 56 to 87 g ha^{-1}, respectively (Table 4). Uptake of Fe, Mn and Cu by grain and straw of hybrid rice were non-significant where as Zn uptake was significant at 40 to 60 kg S ha$^{-1.}$ The per cent response to Fe, Mn, Zn and Cu uptake by hybrid rice over control was 52, 29, 43 and 55 per cent, respectively.

Potato

Total uptake of Fe, Mn, Zn and Cu by potato in control was 1930, 494, 191 and 35 g ha^{-1}, respectively. With application of S, these values were increased to 2620, 616, 244 and 38 g ha^{-1}, respectively at of 60 kg S ha^{-1} applied through gromor bentonite S pastilles. The corresponding values of per cent increase over control for Fe, Mn, Zn and Cu were 36, 25, 28 and 9 per cent, respectively (Table 4).

Green gram

Uptake of Fe, Mn, Zn and Cu by green gram (residual) in control was 323, 182, 49 and 12 g ha^{-1}, respectively. With application of S, the uptake values were increased significantly which ranged from 407-846 for Fe, 226-575 for Mn, 62-115 for Zn and 15-19 g ha^{-1} for Cu. The per cent response to Fe, Mn and Zn uptake by green gram

Table 4. Effect of different sources and levels of Sulphur on Fe, Mn, Zn and Cu uptake (g ha^{-1}) by hybrid rice, potato, green gram

Treatment	Rice											
	Grain (g ha^{-1})				Straw (g ha^{-1})				Total K (kg ha^{-1})			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1	230	96	65	27	350	670	110	29	580	766	175	56
T_2	340	111	70	33	410	620	140	35	750	731	210	68
T_3	460	145	100	34	400	820	160	38	860	965	260	72
T_4	310	104	80	36	370	670	160	32	680	774	240	68
T_5	330	114	80	30	360	680	160	36	690	794	240	66
T_6	350	96	80	36	520	630	190	39	870	726	270	75
T_7	400	116	90	42	480	870	160	45	880	986	250	87
T_8	290	104	60	31	430	660	160	33	720	764	220	64
CD	**NS**	**NS**	**20**	**NS**	**NS**	**NS**	**NS**	**5**				
					Potato							
T_1	220	44	37	11	1710	450	154	24	1930	494	191	35
T_2	270	47	52	9	2010	500	174	26	2280	547	226	35
T_3	280	52	53	11	2610	710	226	46	2890	762	279	57
T_4	300	48	45	10	2670	640	202	42	2970	688	247	52
T_5	400	46	44	10	1750	400	154	26	2150	446	198	36
T_6	370	55	60	13	2280	610	212	33	2650	665	272	46
T_7	260	46	53	8	2360	570	191	30	2620	616	244	38
T_8	320	50	54	10	2050	590	273	32	2370	640	327	42
CD	**NS**	**6**	**NS**	**NS**	**595**	**170**	**NS**	**NS**				
					Green gram							
T_1	13	12	9	2	310	170	40	10	323	182	49	12
T_2	16	17	13	2	660	230	60	13	676	247	73	15
T_3	19	22	14	3	480	400	60	14	499	422	74	17
T_4	20	23	14	3	680	320	100	16	700	343	114	19
T_5	16	19	12	3	830	370	70	13	846	389	82	16
T_6	15	25	18	3	590	550	90	12	605	575	108	15
T_7	22	27	25	3	1130	400	90	14	1152	427	115	17
T_8	17	16	12	2	390	210	50	7	407	226	62	9
CD	**2**	**3**	**3**	**0.4**	**57**	**39**	**19**	**1.4**				

over control was more than 100 per cent where as 42 per cent for Cu at 60 kg S ha^{-1} through gromor bentonite S pastilles. Among the S sources, higher uptake of Fe, Mn, Zn and Cu were recorded with gypsum followed by gromor bentonite S pastille and SSP (Table 4).

Effect of treatments on Cumulative yield and SUE of the Cropping sequence

The cumulative crop yield of rice-potato-green gram cropping sequence increased with increasing S levels and ranged from 24.8 to 28.4 t ha^{-1} in S treatments as against 22.7 t ha^{-1} in control. The cumulative grain yield response to S application over control ranged from 2.1 to 5.7 t ha^{-1}. Highest cumulative grain yield response was recorded in T_7 (gromor bentonite S pastille @ 60 kg S ha^{1}) followed by T_6. Cumulative S uptake values increased with increasing levels of S (Table 5). The cumulative S uptake values ranged from 50.2 to 71.0 kg ha^{-1} in S treatments and 42.2 kg ha^{-1} in control. Cumulative S uptake response to S levels over control ranged from 8. 0 to 28.8 kg ha^{-1}.

Sulphur use efficiency (SUE) decreased with increasing levels of S. In gromor bentonite S pastilles and gypsum treatments, the SUE ranged from 35.9 to 74.6 per cent and 47.3 to 77.4 per cent, respectively. Application of SSP recorded lowest SUE value of 25.2 per cent. The RAE values were calculated by taking gypsum @ 40 kg S ha^{-1} as standard. The RAE by rice-potato-green gram system showed an increasing trend with increasing levels of S. The RAE in gromor bentonite S pastilles treated soils was higher than gypsum at same level of S application. Highest RAE of 123 per cent was recorded at 60 kg S ha^{-1} with gromor bentonite S pastilles. The ASR by rice-potato-green gram system

Table 5. Effect of S bentonite pastilles on SUE, RAE and ASR of hybrid rice-potato-green gram system

Treatments	Cumulative grain yield (t ha^{-1})	Cumulative grain yield Response (t ha^{-1})	Cumulative S Uptake (kg ha^{-1})	Cumulative S Uptake Response (kg ha^{-1})	Total S applied (kg ha^{-1})	SUE (%)	RAE (%)	ASR (%)
T_1	22.7	-	42.2	-	-	-	-	-
T_2	25.8	3.1	50.2	8.0	40	74.6	64.8	20.0
T_3	27.3	4.6	60.0	18.0	80	57.7	100.0	22.5
T_4	27.1	4.4	57.2	15.1	120	35.9	93.4	12.6
T_5	25.8	3.1	55.5	13.3	40	77.4	67.1	33.5
T_6	27.8	5.1	66.6	24.4	80	61.9	107.4	30.7
T_7	28.4	5.7	71.0	28.8	120	47.3	123.0	24.0
T_8	24.8	2.1	54.7	12.5	80	25.2	43.7	15.7

Table 6. Available sulphur in soil as affected by different levels and sources of sulphur after harvest of hybrid rice-potato-green gram cropping sequence

	pH		Available S (mg kg^{-1})		
Treatments	**0-15 cm**	**15-30 cm**	**0-15**	**15-30 cm**	**30-45 cm**
T_1	5.0	6.7	3.4	10.0	12.8
T_2	5.4	6.5	18.5	19.6	15.6
T_3	5.1	6.8	20.0	21.5	17.5
T_4	5.3	6.8	22.0	23.0	25.0
T_5	5.4	6.7	24.8	15.6	14.0
T_6	5.1	6.5	30.6	15.6	15.0
T_7	5.2	6.1	35.6	17.0	15.0
T_8	5.6	6.6	23.6	12.6	14.0
Initial	4.70	6.8	3.51	11.0	13.0
CD	**NS**	**NS**	**6.61**	**7.50**	**NS**

decreased with increasing levels of S. The ASR with gromor bentonite S pastille at 20 kg S ha^{-1} was higher as compared to gypsum or SSP. The superiority of gromor bentonite S pastille over other S fertilizers (gypsum, SSP) may be due to its high concentration, slow release pattern and minimum leaching loss.

Available S

Available S content in soil after three years in control was 3.4 mg kg^{-1} as against the initial value of 3.4 mg kg^{-1} indicating the depletion of native S by 3 per cent due to intensive rice-potato-green gram cropping system (Table 6). Available S increased significantly from 3.4 to 35.6 mg kg^{-1} with increasing levels of S. The increase in available S was due to increasing amount of added S through S sources. The building up in available S in gromor bentonite S pastilles treatments were higher than gypsum may be due to higher leaching loss of S in later source. On the other hand, the available S in SSP was higher than gypsum.

Depth wise distribution of available S

The data in Table 6 revealed an increase in available S status up to 30 cm depth which ranged from 12 to 19.6 mg kg^{-1}, but declined at 45 cm. This could be explained by the leaching of soluble S below the root rhizosphere with irrigation water and or rainfall over the three cropping years. Available S increased with increasing levels of S in all depths. However, the magnitude of available S in gromor bentonite S pastilles was higher than gypsum at 0-15 cm depth, but a reverse trend was observed in lower depths (30 and 45 cm), which indicates slow movement of available S to lower depth in gromor bentonite S pastilles-treated soils.

The results suggest that due to recycling of higher root biomass in gromor bentonite S pastilles, the binding capacity of surface soil was increased resulting in less movement of S along with clay fraction of the soils. Low solubility of gromor bentonite S pastilles further enhanced

S use efficiency resulting in less leaching.

CONCLUSION

On the basis of the foregoing results, it can be concluded that application of S significantly increased the grain and straw yield, uptake of N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu by hybrid rice-potato-green gram cropping system. A dose of 60 kg S ha^{-1} was ideal for hybrid rice and 40 kg S ha^{-1} for potato. Residual effect of gromor bentonite S pastille on succeeding green gram was higher than gypsum or SSP. Among the three sources, gromor bentonite S pastille was found to be best source of S followed by gypsum and SSP. Hence S bentonite could be recommended as a source of S fertilizer because of its high concentration, slow release and minimum leaching loss.

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