Assessing sulphur deficiencies in soils and on-farm yield response to sulphur under rice (Oryza sativa)-wheat (Triticum aestivum) system in Garhwal region

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Research Paper

Assessing sulphur deficiencies in soils and on-farm yield response to sulphur under rice *(Oryza sativa)*–wheat *(Triticum aestivum)* system in Garhwal region

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ABSTRACT

Sulphur (S) deficiency in rice (*Oryza sativa* L.)–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol} growing areas of Garhwal region of Western Himalayan zone was delineated during 2003-2007. For this, 1191 soil samples (0-15 cm depth) were collected from Fakot and Chamba Agricultural Development Blocks (ADBs) of New Tehri Districts and analyzed for soil OC and available S content. Of the total, > 40% soils were low in OC content and occurrence of S deficiency was also associated with soil OC content. On S deficient soils of village Jajal (Fakot, ADB) and village Nagini (Chamba, ADB), on-farm experiments were conducted during 2004 to 2007 with four levels of S (0, 15, 30 and 45 kg S/ha) in a randomized block design under rice-wheat system. Rice yield increased ($p<0.05$) by 1.15 to 1.42 t/ha at Jajal and 1.14 to 1.55 t/ha at Nagini with 30 and 45 kg S application over no-S application in different years. Succeeding wheat yields also increased (0.66 to 1.27 t/ha and 0.41 to 1.16 t/ha, respectively) under residual S (30 or 45 kg S/ha) plots. Whereas, lower S application dose (15 kg/ha) did not leave residual effect on the succeeding wheat crop. Compared with (no-S), cumulative rice-wheat system S uptake at 30 and 45 kg S/ha was also higher by 102% to 134% at Jajal and 90% to 123% at Nagini. Skipping S application or under application of 15 kg S in fertilization schedule caused depletion in available S content of the soils by 1.0 to 2.7 mg/kg over initial S status at these study sites. After 03-crop cycles, apparent S balance was positive (10 to 57.3 kg/ha at Jajal and 14.7 to 67.0 kg/ha at Nagini) when rice received external fertilizer S input. On an average, value cost ratio (VCR) for rice-wheat system due to S fertilization ranged between ₹ 59 to 107 /₹ invested in S at Jajal and ₹ 48 to 101/₹invested in S at Nagini indicating the necessity of inclusion of S in fertilization schedule for sustained yield and profit of rice-wheat system in Garhwal region.

Key words: Apparent S balance, Garhwal region, Rice–wheat cropping system, S use efficiency

Rice-wheat (RW) cropping system is predominant in lower and middle hills and valleys of Garhwal region. Surveys conducted in the rice-wheat growing areas of Garhwal region indicate that farmers' fertilizer management practices are skewed towards N and P, and S application is almost neglected (Singh and Gangwar, 2011). Sulphur deficiency is increasing with each passing year, which is restricting crop yields, quality of produce, nutrient use efficiency and economic returns (Tandon, 2011). Although the information on magnitude of S deficiency particularly in Garhwal region is scanty, yet studies conducted by TSI-FAI-IFA and ICAR in other part of the country have already indicated that more than 70% soil samples are either deficient or marginal (moving towards deficiency) in plant available S. Reasons assigned for such results are very well corroborated with the results of farmers' participatory surveys in the Indo-Gangetic Plain (IGP) by Sharma, 2003 that a rice-wheat system (RW system) producing, on average, 3.92 t/ha rice and 3.95 t/ha wheat in a year removes annually about 331.0 thousand tonnes of S, whereas its application is largely ignored. Thus, increasing S deficiency in soil as one of the major cause for declining yield in long-term experiments (Hobbs and Morris, 1996; Swarup and Wanjari, 2000) seems to be true as a result of excess withdrawals than its replenishments. Further, studies conducted under AICRP-IFS underlined the importance of S in sustaining high yield levels of rice-wheat system, where yields of both crops declined in the plots receiving NPK and Zn at recommended rates when available S content of the soil was depleted below the threshold level (Tiwari *et al.,* 2006). On the other hand, use of S through fertilizer (Single superphosphate) or other available sources, however, reversed the yield trends (Dwivedi *et al.* 2001; Singh and Mishra, 2010). In view of above, the present study was undertaken in the intensively

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rice-wheat cultivated areas of Garhwal region, to assess the magnitude of S deficiency, and to see the effect of S management on RW system productivity, profitability, changes in soil S status and apparent S balance at farmers' field.

MATERIALS AND METHODS

The study was undertaken in the rice–wheat dominated areas of Garhwal region. For this, representative district New Tehri was chosen, as crop management strategies, including nutrient management, evolved for this district could be extrapolated to the entire Garhwal region.

Delineation of S deficiency

To assess the extent of on- farm S deficiency, soil sampling was done in Fakot and Chamba Agricultural Development Blocks (ADBs) of the district New Tehri during 2003-04 and 2006-07. For this purpose, villages having at least 50% gross-cropped area under RW system, and field having RW system for more than two consecutive years was the criterion for selection of farmers' fields (0-15 cm soil depth). Positional representation of surveyed villages is given in Fig.1. Soil samples were collected during May and June, i.e., after harvest of wheat crop and the total numbers of fields selected for soil sampling were 671 in Fakot and 702 in Chamba ADBs.

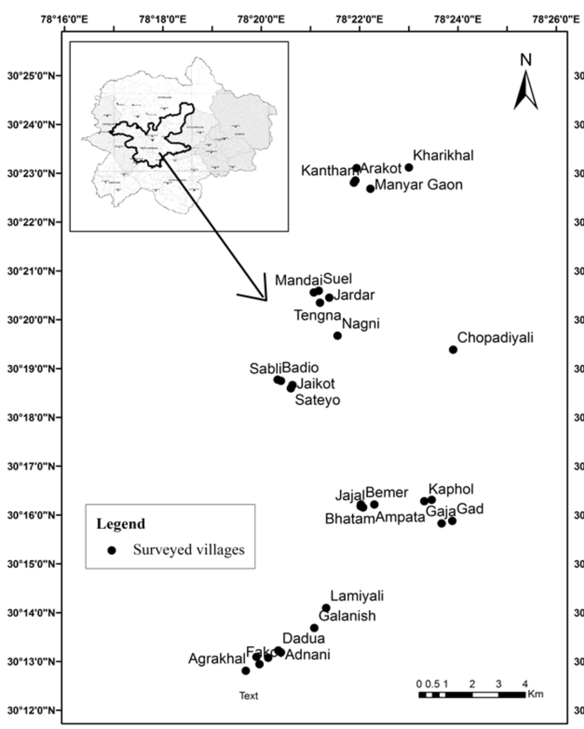

Fig. 1. Positional representation of surveyed villages in Garhwal Region Inset shows Garhwal region with highlighted New Tehri district boundary.

On-farm experiments

On-farm experiments were conducted under RW system on S-deficient fields in Jajal village (Fakot, ADB) and Nagini village (Chamba, ADB) for 03 consecutive years i.e., 2004 to 2007 on same layout. Soil of the experimental site was loam to sandy loam in texture having neutral reaction (pH 6.5-7.0), electrical conductivity (0.20-0.21 dS/m), medium soil organic carbon (0.52-0.59%) and exchangeable K (0.15-0.19 me/100g), and low in Olsen P (8.13-9.06 mg/kg) and available S (6.12-10.0 mg/kg) content.

At each experimental site, four levels of S (0, 15, 30 and 45 kg S/ha) were evaluated in a randomized block design having five replications. The plot-size was 8 m × 6 m. Single superphosphate (12% S, 6.99% P) was used to apply S to rice crop only and residual effect of S was measured on succeeding wheat. A uniform dose of 120 kg N, 26 kg P and 50 kg K/ha was applied to both rice and wheat. Urea (46.4% N), di-ammonium phosphate (18% N, 20.09% P), or single superphosphate as per treatment, and muriate of potash (49.8% K) were used to supply N, P and K, respectively. A uniform dose of 5 kg Zn/ha as zinc chloride (65% Zn) was also applied to rice.

Twenty five day-old seedlings of rice were transplanted at 20×15 cm spacing in puddled plots during first week of July. Rice was harvested during last week of October. Succeeding wheat was sown in 20 cm apart rows, using 100 kg seed/ha, during second fortnight of November at all locations. The wheat crop was harvested at maturity during second fortnight of April. A net plot area of 30 m^2 (6 m × 5 m) was marked for harvesting of grain yield.

Soil samples collected from different villages, and from on-farm experimental plots after harvest of each wheat crop were analyzed for available S content (Williams and Steinbergs, 1969) and OC content (Walkley and Black's method). Initial soil samples collected from on-farm experiments were also tested for pH and electrical conductivity (1:2 soil-water suspension), available P (0.5 *M* $NaHCO_3$, pH 8.5) and available K (1*N* NH_4OAc, pH 7.0) by following standard analytical procedures (Page *et al.*, 1982). The grain and straw samples collected from each plot were washed thoroughly with tap water, 0.05 *N* HCl solution and de-ionised water in succession, and dried at 70^0 C in a hot-air oven. The dried samples were ground in a stainless steel Wiley mill, digested in a di-acid mixture ($HClO_4$ and HNO_3 mixed in 4:1 ratio) and aqueous extracts were prepared. Total S content in the extracts was then determined turbidimetrically (Chesnin and Yien, 1950) using an UV-VIS spectrophotometer.

'F-test' was used for treatment comparisons in the on-farm experiments, following the procedures of randomized block design (Sukhatme *et al.*, 1984). Whereas, standard error (SE±) was computed for mean available S content under different organic carbon ranges (Fig. 2).

In order to quantify the effect of fertilizer S on the S use efficiencies in rice and in RW system, computations were made using following equations:

$$AE_S = \Delta Y / F_S \quad .. (1)$$

Where,

AE_S is the agronomic efficiency, often termed as incremental efficiency of applied S fertilizer, ΔY is the incremental yield due to fertilizer S input, F_S the amount of fertilizer S applied. ΔY and F_S are expressed as kg/ha.

Recovery efficiency of S (RE_s) in rice as well as RW system was computed as the difference in S uptake by the above-ground portions of S fertilized and unfertilized crop (ΔU) and expressed as the percentage of S fertilizer applied.

$$AR_S = \Delta U / F_S \times 100 \quad .. (2)$$

The value cost ratio (VCR) of S application for rice as well as in RW system was also worked out as per follows:

$$VCR = ANR_{R\ or\ Rw} / Ps \quad .. (3)$$

Where, $ANR_{R\ or\ Rw}$ is the additional net return ( ) in rice or RW system due to S application and P_S is the price of sulphur applied (₹).

An apparent nutrient balance sheet at the end of the 03 year that experiment was calculated by subtracting the nutrient removed in the crops from added through fertilizer, crop residue, irrigation water and rainfall.

RESULTS AND DISCUSSION

Soil OC content and its relationship with available S

The mean soil OC in Fakot and Chamba ADBs was 0.53±0.08% and 0.51±0.05%, respectively (Data not shown). Considering <0.50% OC as thresh hold content (Subba Rao, 1993), 44.4% soils in Fakot and 40.2% soils in Chamba ADBs were found to be lying herein and were hence rated as low in OC content. Occurrence of S deficiency was also associated with soil OC content, and the soil samples having low OC (<0.5%) exhibited greater S deficiency (40.6% at Fakot and 36.2% at Chamba), whereas the reverse was true for high OC (>0.75%) soils (4.7% at Fakot and 1.3% at Chamba) (Fig. 2). These results are very well corroborated with earlier findings of TSI, 1994; Tandon, 2011; Yadav *et al.*, 2001 which reveals that the major factors leading to S deficiency under intensive cropping systems are coarse soil texture, low organic matter, greater S removals as a result of intensive cropping and neglect of S additions through fertilizers or manures. The soils of studied locations were rocky along with loamy sand to sandy loam (coarse-textured) with low soil OC content having lower SO_4-S retention capacity, particularly in surface layers (Till, 2011) which leads to S leaching. Since organic-S fraction in the soil is positively related to organic matter status (Pasricha and Sarkar, ₹ 2009) which is generally considered the important donor pool to available S (Tripathi and Hazara, 2000), higher magnitude of S deficiencies are expected in the soils containing low OC content.

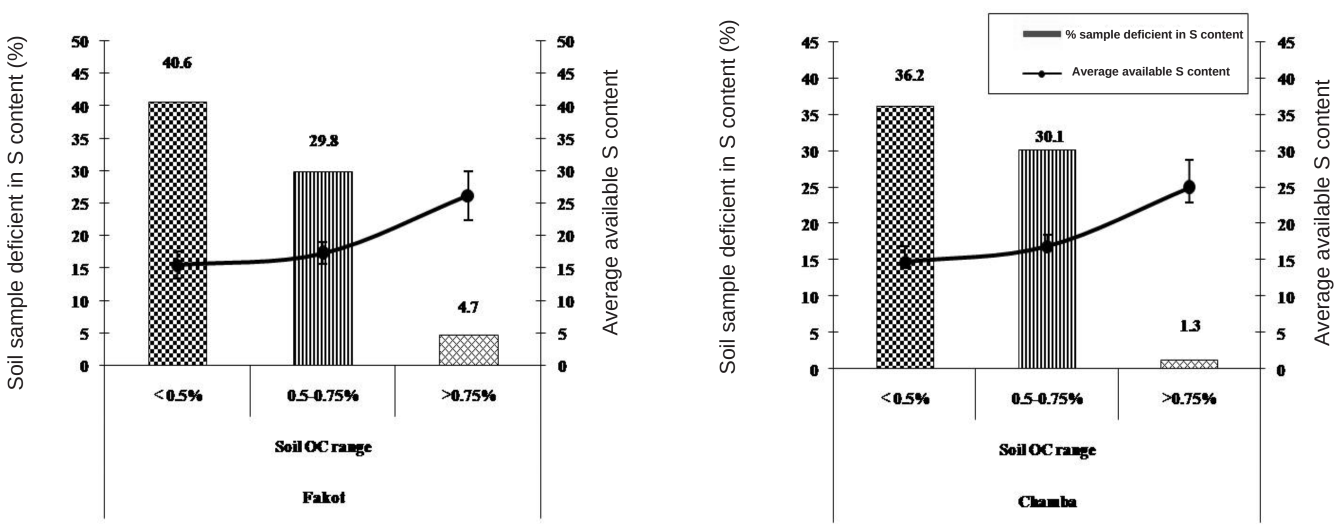

Fig. 2. Relationship between soil OC content and S deficiency under surveyed areas of Fakot and Chamba. Bar indicates standard error.

Direct effect of S on rice yield

At both the study sites, grain increased significantly (p<0.05) up to 30 kg S application, however, the magnitudes of response varied in accordance to initial S status of the soils. Averaged across the years, yield response to this application rate (30 kg/ha) was to the tune of 1.17 t/ha and 1.29 t/ha over no-S application rates at Jajal and Nagini, respectively. Increasing S rates beyond 30 kg could not bring any significant yield gain at both the experimental sites. Unlike earlier reports which indicated that cereals have lower S requirement (10-30 kg/ha) than many other agricultural crops (Singh, 2001), our results corroborated with the findings of Withers *et al., 1995* in a way that adequate level of S is considered necessary not only for satisfactory crop growth but also to ensure the presence of optimum levels of S-containing amino acids in the grain. Significantly (p<0.05) large yield responses of rice to S fertilizer observed in these on-farm experiments emphasize that, despite relatively low S requirement, the productivity of the staple food grain may be drastically reduced by an inadequate supply of S. Higher yield response and agronomic efficiency of rice to applied S particularly at 15 and 30 kg S rate at Nagini as compared to Jajal (Table 1) was associated with the difference in initial S content of the soil, that was distinctly greater (10.0 mg/kg) at Jajal. In fact, crops grown on low S soils utilize fertilizer S more efficiently (Nad and Goswami, 1985), and thus crop responses to S applied at a particular rate largely depend on the severity of S deficiency in the soil (Nambiar, 1994).

The harvest index computed for assessing economic yield gain in reference to total biological yield indicated that highest values were with 45 kg S application. Here, it may be argued that balanced nutrition of NPK along with S restricted luxuriant crop foliage growth and converted

Table 1. Direct effect of sulphur application on rice and residual on wheat productivity at experimental sites of Garhwal region

Treatment	1st year	2nd year	3rd year	Pooled	Harvest index	Agronomic S use efficiency (kg grain/kg S)
			Rice grain yield (t/ha)			
Jajal						
S_0	3.59	3.34	3.01	3.32	0.42	-
S_{15}	4.24	3.92	3.76	3.98	0.43	44.0
S_{30}	4.78	4.50	4.16	4.48	0.45	38.8
S_{45}	4.94	4.76	4.42	4.72	0.47	30.9
SEm±	0.15	0.10	0.11	0.12	0.004	1.9
CD (P=0.05)	0.46	0.31	0.32	0.37	0.012	6.8
Nagini						
S_0	3.32	3.01	2.75	3.03	0.41	-
S_{15}	3.94	3.69	3.53	3.72	0.43	46.0
S_{30}	4.46	4.49	3.98	4.31	0.45	42.9
S_{45}	4.48	4.56	4.12	4.40	0.46	30.3
SEm±	0.14	0.10	0.13	0.14	0.002	2.0
CD (P=0.05)	0.43	0.32	0.41	0.41	0.005	7.4
			Wheat grain yield (t/ha)†			
Jajal						
S_0	2.71	2.63	2.53	2.63	0.43	-
S_{15}	3.14	3.02	2.96	3.043	0.45	27.7
S_{30}	3.37	3.43	3.48	3.43	0.46	26.7
S_{45}	3.55	3.73	3.80	3.69	0.46	23.7
SEm±	0.15	0.10	0.16	0.13	0.007	0.6
CD (P=0.05)	46	0.36	0.49	0.41	0.021	2.4
Nagini						
S_0	2.48	2.19	2.08	2.25	0.42	-
S_{15}	2.58	2.52	2.42	2.51	0.43	17.2
S_{30}	2.89	2.83	2.88	2.87	0.46	20.5
S_{45}	3.07	3.20	3.24	3.17	0.45	20.3
SEm±	0.11	0.12	0.12	0.12	0.008	0.6
CD (P=0.05)	0.32	0.37	0.36	0.34	0.024	2.1

† S was applied to rice only, the effect on wheat are residual

more photosynthats towards economic yield. Increased grain S uptake as compared to straw (9 to 18%) at 30 to 45 kg S application rate recorded in the present study may be envisaged as S fertilization led more balanced nutrition and transportation of photosynthates towards economic part of the plant (Table 2).

Residual effect of S on wheat

Application of S at 30 or 45 kg/ha to rice brought significant ($p<0.05$) yield increase in succeeding wheat due to residual effect at both the sites. However, the quantum of gain depended on initial soil status. Compared with no-S treatment, 0.84, 1.10 and 1.27 t/ha increase in wheat yield was recorded with highest rate of S application at Jajal during first, second and third year, respectively. Similar yield gain with 45 kg S/ha application was of 0.59, 1.00 and 1.16 t/ha, respectively at Nagini (Table 1). Pooled over the years, use of 30 kg to 45 kg S /ha had 27 to 31% and more yield over no-S (Control) at these locations. But the residual responses in wheat were not found significant ($p<0.05$), when S was applied below 30 kg S/ha. Substantial yield increases in wheat grown on S- fertilized rice plots imply that sufficient amount of added S remained unused in soil even after harvest of directly fertilized rice crop (Biswas and Tewatia, 1991; Tiwari *et al.*, 2006). Increase in harvest index of wheat (Table 1) and soil S content after wheat harvest in 30 or 45 kg /ha S-treated plots at both the sites support this contention (Table 3). Interestingly, S use efficiency in residual wheat (kg grain/kg S) increased with increasing S rates at Nagini up to 30 kg S application rate, whereas it remained unchanged upto 30 kg S application at Jajal and significantly decreased ($p<0.05$) beyond 30 kg S application rate. These results inferred that (i) soil with relatively low S status produced higher residual response, and (ii) low rates of S fertilization (below 30 kg S/ha) in rice failed to leave sufficient S residue to be translated into agronomic yield in the succeeding wheat crop particularly on soils having lower S content.

Effect on S uptake and fertilizer S recovery

Total S uptake of the RW system during 03 crop cycle ranged between 50.7 to 118.5 kg/ha and 47.6 to 106.1 kg/ha at Jajal and Nagini, respectively. Each increment of S rates to rice brought increased S uptake up to its 45 kg application rate by grain and straw of rice as well as in residual wheat at both the sites. Compared with control, total S uptake at 45 kg S/ha was higher by 174% and 137% in rice and 109% and 113% in wheat at Jajal and Nagini, respectively. In general, share of S uptake to rice grain was relatively higher as compared to straw particularly under S applied plots (15 to 45 kg S/ha) whereas reverse was true in case of wheat crop at both the locations (Table 2). The apparent recovery of S (REs) under RW system, was increased up to 30 kg S/ha application rate and thereafter declined at both the locations. The increasing REs up to 30 kg S/ha rates at both the locations indicates that application of 30 kg S was sufficient to meet the crop S requirement and thereafter efficiency reduces with each incremental S use.

Effect on soil S status and apparent balance sheet

At the onset of the experiment, available S status of the experimental site at Jajal and Nagini was 10 and 6.4 mg/kg, respectively. A gradual increase in soil S status was noticed over the years in 30 (8 to 19%) or 45 kg/ha S (11 to 30%) applied plots, respectively. Continuous application of 45 kg S/ha to rice for three RW cycle, however,

Table 2. Total S uptake from 03 RW cycle at experimental sites of Garhwal region

Treatment	S uptake from rice (kg/ha)			S uptake from wheat (kg/ha)			System S uptake (kg/ha)	Apparent S recovery (%)
	Grain	Straw	Total	Grain	Straw	Total		
Jajal								
S_0	8.4	10.6	19.0	13.7	18.0	31.7	50.7	-
S_{15}	13.3	15.5	28.7	21.0	21.9	42.9	71.6	46.4
S_{30}	24.2	21.9	46.2	26.6	29.6	56.2	102.4	57.4
S_{45}	27.2	24.9	52.1	31.0	35.4	66.4	118.5	50.2
SEm$\pm$	0.7	0.8	1.8	1.2	1.7	3.4	5.0	2.2
CD (P=0.05)	2.8	2.4	5.1	3.8	5.2	9.4	14.5	8.1
Nagini								
S_0	9.0	10.8	19.8	12.1	15.7	27.8	47.6	-
S_{15}	14.7	12.9	27.6	16.4	21.3	37.7	65.3	39.2
S_{30}	22.0	19.6	41.6	22.2	26.9	49.0	90.6	47.8
S_{45}	25.4	21.5	47.0	26.9	32.2	59.1	106.1	43.3
SEm$\pm$	0.9	0.6	1.9	1.4	1.6	3.4	4.9	1.3
CD (P=0.05)	2.9	1.8	5.1	4.3	5.4	9.9	15.1	4.8

raised the S status up to 14.3 mg/kg (Jajal) and 11.0 mg/kg (Nagini) after third wheat harvest (Table 3). On the other hand, a decline in soil S status (-3 to -37%) over initial S content after 03 RW cycle was noticed with 15 kg/ha S application or skipping of S from fertilization schedule at these sites. Decline in S content over the years further emphasize that inadequate or omitting S application from fertilization schedule have not only adverse effect on system productivity but also on the inherent soil S pool (Singh and Mishra, 2010).

During the 03 years of experimentation, S addition through fertilizer, residue and irrigation water were in the range of 36 to 178 kg/ha and 93 to 173 kg/ha at Jajal and Nagini, respectively. Apparent balance sheet, computed as sulphur addition from different sources less sulphur off-take in the crops, revealed positive S balance at all rates of S application at both the locations. On the other hand, negative S balances were noticed (-14.3 to -14.8 kg S/ha) under S skipped plots (Table 4). Negative S balance under no-S plots at both the sites further indicates the possible depletion of sulphur from soil reserves when its application is omitted. Further, gradual decline in soil S content under no-S (Control) or 15 kg S applied plots (Table 3) cautioned here that these soil contributions will decrease due to soil mining in the long run. Such results are a reminder of the fact that nutrient removal does take place ever when a nutrient is not applied, though it's this phenomenon cannot go on for even and is the greatest threat to soil fertility management.

Economics of S application

The value cost ratio (VCR) of rice due to S application ranged between 43.8 to 74.9 at Jajal and 41.1 to 71.0 at Nagini in different years (Table 5). Averaged over the years, it decreased with increasing S rates and maximum being at 15 kg S application rates (65.7 and 65.3 at Jajal

Table 3. Annual change in available soil S content (kg/ha) due to S fertilization under RW system at on-farm experimental sites of Garhwal region

Treatment	Initial status	After 1st RW cycle	After 2nd RW cycle	After 3rd RW cycle	% change over initial status		
					After 1st RW cycle	After 2nd RW cycle	After 3rd RW cycle
Jajal							
S_0	10	9.1	7.6	7.3	(-)10	(-) 32	(-) 37
S_{15}	10	9.7	8.9	9.4	(-) 3	(-) 12	(-) 6
S_{30}	10	10.9	11.1	12.4	(+) 8	(+) 10	(+)19
S_{45}	10	11.2	12.8	14.3	(+) 11	(+) 22	(+) 30
SEm±	-	0.4	0.5	0.5	-	-	-
CD (P=0.05)	-	1.1	1.6	1.4	-	-	-
Nagini							
S_0	6.4	5.6	5	5.4	(-) 14	(-) 28	(-) 19
S_{15}	6.4	5.9	6	6.2	(-) 9	(-) 7	(-) 3
S_{30}	6.4	7.2	8.8	9.2	(+) 11	(+) 27	(+) 30
S_{45}	6.4	7.8	10.4	11.0	(+)18	(+) 38	(+) 42
SEm±	-	0.4	0.5	0.6	-	-	-
CD (P=0.05)	-	1.2	1.5	1.7	-	-	-

Table 4. Apparent S balance sheet under RW system at experimental sites of Garhwal region

S rate (kg/ha)	Total S input in 03 years (kg/ha)			Total (kg/ha)	Total S uptake (kg/ha)	Balance (kg/ha)
	Fertilizer	Residue	Irrigation			
Jajal						
S_0	0	5.0	30.9	35.9	50.7	(-) 14.8
S_{15}	45	7.2	30.9	82.1	71.6	(+) 10.5
S_{30}	90	10.0	30.9	130.9	102.4	(+) 28.5
S_{45}	135	11.9	30.9	177.8	118.5	(+) 59.3
Nagini						
S_0	0	4.8	28.5	33.3	47.6	(-)14.3
S_{15}	45	6.5	28.5	80.0	65.3	(+) 14.7
S_{30}	90	9.0	28.5	126.5	90.6	(+) 35.9
S_{45}	135	10.6	28.5	173.1	106.1	(+) 67.0

Table 5. Value cost ratio (VCR) (return/₹ invested in S) of sulphur fertilization for RW system at experimental sites of Garhwal region

Treatment	Direct on rice				Residual on wheat				Total for the system			
	1st year	2nd year	3rd year	Mean	1st year	2nd year	3rd year	Mean	1st year	2nd year	3rd year	Mean
Jajal												
S_0	-	-	-	-	-	-	-	-	-	-	-	-
S_{15}	64.9	57.2	74.9	65.7	52.4	48.1	53.8	51.4	58.7	52.6	64.3	58.5
S_{30}	58.9	55.7	56.1	56.9	41.1	48.2	59.6	49.6	100.0	103.8	115.7	106.5
S_{45}	44.3	45.3	43.8	44.5	36.3	45.8	52.5	44.8	80.6	91.0	96.3	89.3
SEm±	2.4	1.9	2.7	2.2	2.5	1.4	1.5	1.4	5.0	4.6	5.3	5.0
CD (P=0.05)	8.7	6.8	9.8	8.1	9.2	NS	5.4	5.2	18.2	16.7	19.2	18.2
Nagini												
S_0	-	-	-	-	-	-	-	-	-	-	-	-
S_{15}	61.7	66.1	68.1	65.3	13.5	38.0	42.4	31.3	37.6	52.0	55.3	48.3
S_{30}	55.9	71.0	55.9	60.9	27.3	39.7	51.7	39.6	83.2	110.6	107.6	100.5
S_{45}	37.6	49.7	41.1	42.8	25.2	40.1	49.7	38.3	62.8	89.8	90.8	81.1
SEm±	1.8	1.6	1.9	2.2	1.2	1.5	1.7	2.0	2.8	4.5	3.9	4.2
CD (P=0.05)	6.4	5.8	14.2	6.8	4.2	NS	6.4	7.2	10.1	16.1	14.2	15.3

and Nagini, respectively). Such benefits were much more when residual response on succeeding wheat crop was taken into account. Unlike rice, VCR values in wheat were increased up to 30 kg S application rates, and thereafter, declined. Averaged across the years, VCR for RW system was maximum at 30 kg S application rates (₹100.5 to 106.5 /₹ invested in S), showing that maximum monitory benefit can be obtained by spending each ₹ on S at 30 kg S application rate.

Findings of this study inferred that soils of rice-wheat growing areas of Garhwal region are suffering from varying degree of S deficiencies and the magnitude is larger in the soils containing low OC content. On farm experiments conducted in the region suggest that 30 kg S application to rice had pronounced effect on rice as well as on succeeding wheat productivity under RW system along with maximum monetary benefits. Substantial direct and residual responses to S fertilizer in rice-wheat system under on-farm studies emphasize the necessity of inclusion of S in fertilization schedule for sustained RW system productivity and soil health.

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