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1 author:

Vinod K. Singh
Indian Agricultural Research Institute

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Delineation of sulphur deficiencies in Trans-Gangetic Plain and on-farm sulphur management for higher productivity and profits in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system

V K SINGH[1] and V KUMAR[2]

Project Directorate for Farming Systems Research, Modipuram, Meerut, Uttar Pradesh 250 110

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ABSTRACT

In the view of assessing the extent of S deficiency in rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) growing areas of Trans- Gangetic Plain (TGP) zone and to measure the S response of rice-wheat system on farmers' field, 1191 soil samples were collected from Rai and Bapoli Agricultural Development Blocks (ADBs) of Sonipat and Panipat districts. The soil samples (0-15 cm soil profile) were analyzed for soil OC and available S content indicated that more than 60% soils were low in OC content and occurrence of S deficiency was also associated with soil OC content. Farmers' fertilizer management practices were highly imbalanced and skewed towards N and use of S fertilizers was generally negligible (only 17% farmers' apply). On-farm trials conducted on S deficient soils during 2004 to 2007 with four levels of S (0, 15, 30 and 45 kg S/ha) in a randomized block design indicated that S applied at 30 to 45 tonnes/ha, increased rice yields significantly (1.12 to 1.17 tonnes/ha and 1.26 to 1.35 tonnes/ha, respectively) compared with no-S application. Succeeding wheat also showed significant response to residual S at 30 or 45 kg S/ha. Compared with control, total S intake at 45 kg S/ ha was higher by 129% to 154% in rice and 86% to 81% in wheat. Lower S application dose (15 kg/ha) did not leave residual effect on the succeeding wheat crop. Skipping S application caused depletion in available S content of the soils (23 to 42%) over initial S status. After 03-crop cycles, apparent S balance was positive at both the study sites when rice received more than 30 kg/ha S. Substantial yield gains and higher value cost ratio due to S fertilization (₹ 95 to 103 /Re invested in S) was further substantiated with impact studies conducted during 2007 which reveal that more than 33% farmers started using S in fertilization schedule for rice-wheat system.

Key words: Apparent S balance, Rice-wheat, Yield, Value cost ratio, S use efficiency, Soil fertility, Trans-Gangetic Plain

Sulphur (S) is considered to be one of the most limiting nutrients in the intensively cultivated areas. Fertilizer management option particularly devoid of S led to declining sulphur status of Indian soils and its deficiency is becoming more critical with each passing year which is severely restricting crop yield, quality of produce, nutrient use efficiency and economic returns on millions of farms (Tandon 2011). Close to 70% of soil samples analyzed by the ICAR system, TSI-FAI-IFA project and other programs have been found to be either deficient or marginal (moving towards deficiency) in plant available S. Farmers, participatory surveys undertaken in the Indo-Gangetic Plain (IGP) revealed that a rice (*Oryza sativa* L)-wheat (*Triticum aestivum* L.) system (RW system) producing, on average, 3.92 tonnes/ha rice and 3.95 tonnes/ha wheat in a year removes annually about 331.0 thousand tonnes of S whereas its application is largely ignored (Sharman, 2003). Thus, the apprehension of increasing secondary nutrient 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. Studies conducted under AICRP-IFS further 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). Application of S through fertilizer (single super-phosphate) or other available sources, however, reversed the yield trends (Dwivedi *et al.* 2001, Singh and Mishra 2010). In consideration of the above points, the present study was undertaken in the intensively cultivated rice-wheat growing areas of Trans-Gangetic Plain (TGP) zone, to assess the magnitude of S deficiency, and see the effect of S management under rice-wheat cropping system

[1]ICAR National Fellow (vkumarsingh_01@yahoo.com), [2]Technical officer (dr.kumarvinod1961@yahoo.com

on its productivity, profitability, soil S status and apparent S balance at farmers' field.

MATERIALS AND METHOD

The study was undertaken in rice-wheat pre-dominant areas of TGP, transects of the Indo-Gangetic Plain (IGP) region. The representative districts chosen for the study were Sonipat and Panipat. Crop management strategies including nutrient management evolved for these districts could be extrapolated to the entire TGP zone.

To understand farmers' fertilizer management practices in rice-wheat system and to assess the extent of S deficiency, surveys were undertaken in Rai and Bapoli ADBs in district Sonipat and Panipat during 2003-04 and 2006-07. The villages and farmers selected for the diagnostic surveys were chosen from these ADBs, following stratified sampling techniques (Sukhatme *et al.* 1984).

For recording current fertilizer management practices, 40 farmers in each ADB representing different socio-economic groups were selected. Researchers visited selected farmers at 15-day interval during crop growth periods and recorded fertilizer management practices by interviewing the farmers during 2003-04 and 2006-07. In each farmer's field, 1 m × 1 m area was harvested for recording grain yield of rice and wheat. The impact study for different S management technological interventions were also made during 2007.

Soil samples were collected during May and June, i.e., after harvest of wheat in Rai and Bapoli ADBs. Villages having at least 50% gross-cropped area under rice-wheat rotation for more than two consecutive years was the criterion for selection of farmers' fields in these villages. From each selected field, four sub-samples from 0 to 15 cm depth were collected and mixed thoroughly to make one representative homogeneous soil sample. On the whole, 1191 soil samples were collected for S and organic carbon determination.

On-farm experiments were conducted on S-deficient fields in Garh Meerakpur village (Rai, ADB) and Jalalpur I village (Bapoli, ADB) for 03 continuous years, i.e. 2004 to 2007 on same layout. Soil of the experimental site was loamy sand to sandy loam in texture having neutral reaction (pH 7.45 to 7.62), low soil organic carbon (0.42-0.48%), Olsen P (5.12-6.84 mg/kg), available S (4.91-6.8 mg/kg) and medium K (0.11-0.14 me/100g).

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 only and the 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 crop. The crops were grown under irrigated conditions following prevailing standard management practices followed in the region. At maturity, net plot area of 30 m^2 (6 m × 5 m) was harvested for grain and straw yield.

Soil samples collected from different villages for determination of S status, and from on-farm experimental plots after harvest of final wheat crop were analysed 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 tested for pH and electrical conductivity (1:2 soil-water suspension), available P (0.5 *M* $NaHCO_3$, pH 8.5) and available K (I*N* NH_4OAc, pH 7.0), before commencement of the experiments following standard analytical procedures (Page *et al.* 1982). The grain and straw samples collected from each experimental plots were analysed for total S content (Chesnin and Yien 1950).

The data collected during survey were compiled (Fig 1 and 2) and standard error (SE+) for different parameters was computed. 'F-test' was used for treatment comparisons in the on-farm experiments, following the procedures of randomized block design (Sukhatme *et al.* 1984).

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

$$AE_S = DY/ F_S \tag{1}$$

where, AE_S is the agronomic efficiency, DY is the incremental yield due to fertilizer S input (kg/ha), F_S the amount of fertilizer S applied (kg/ha).

Recovery efficiency of S (RE_s) in rice as well as in rice-wheat system was computed using differential method as the difference in S intake by the above-ground portions of S fertilized and unfertilized crop (DU) and expressed as the percentage of S fertilizer applied.

$$RE_S = DU/F_S \times 100 \tag{2}$$

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

$$VCR=ANR_{R\ or\ Rw} / P_S \tag{3}$$

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

An apparent nutrient balance sheet at the end of the 3 year experiment was calculated by subtracting the nutrient removed in the crops from those added in the fertilizer, crop residue, irrigation water and rainfall.

RESULTS AND DISCUSSION

Soil OC content and its relationship with available S

The mean soil OC in Rai and Bapoli ADBs was 0.41+0.07% and 0.44+0.06%, respectively (Data not shown). Considering <0.50% OC as threshhold content (Subba Rao, 1993), 63% in Rai and 60% in Bapoli soils were found and 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

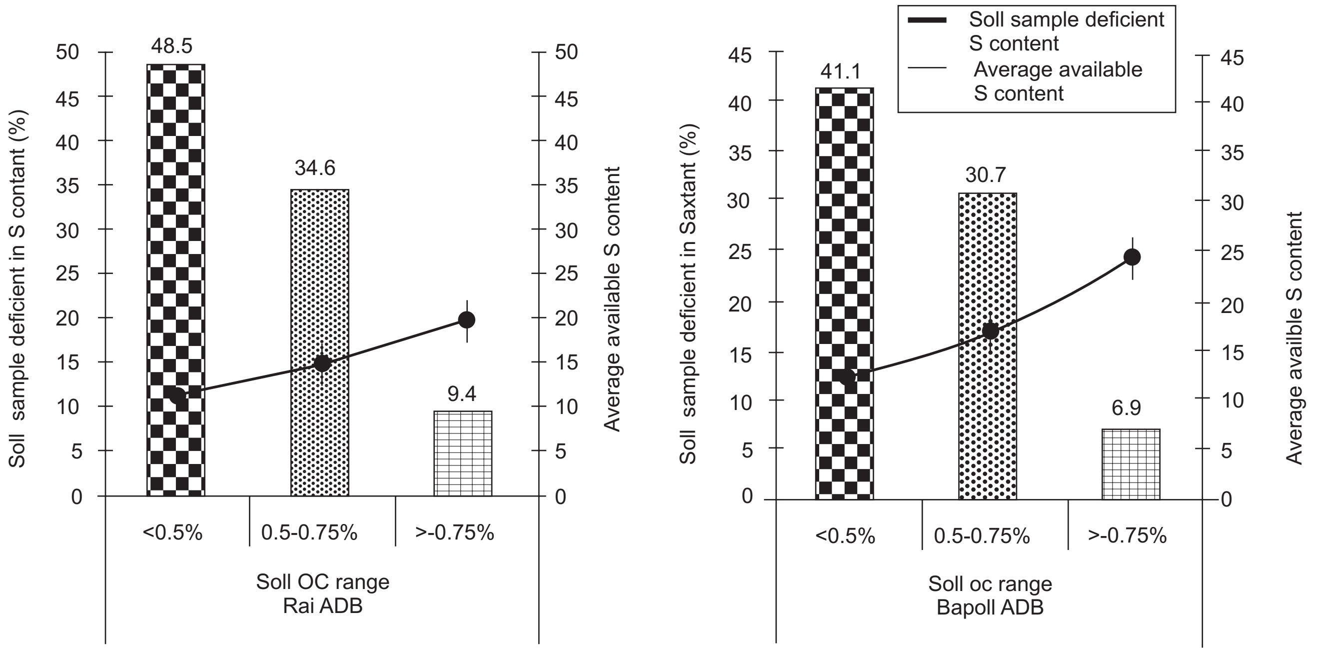

Fig 1 Relationship between soll OC content and S deficiency under surveyed area of Rai and Bapoll ADBs. Bar indicates indicates standard error (n = 40)

(Fig 1). The reverse was true for high OC (>0.75%) soils. 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 coarse-textured (loamy sand to sandy loam) with low soil OC content which has little SO_4-S retention capacity, particularly in surface layers (Till 2010). 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.

Direct effect on rice yield

Use of varying rates of S fertilizer increased the grain yield of rice substantially at both the sites of TGP, however, the magnitudes of response varied in accordance to initial S status of the soils. At Garh Meerakpur site, grain yield of rice with the application of 15 kg S/ha had an additional grain yield of 0.49, 0.74, 0.79 tonne/ha over Control (S_0) during first, second and terminal year of experimentation, respectively. Similar yield response to 15 kg/ha S application was also noticed at Jalalpur I and magnitude of response was in the range of 0.61 to 0.75 tonne/ha in different years. Although, the highest yield were noted with 45 kg S/ha application at both the study sites but increase in S beyond 30 kg/ha could not produce significant yield advantages (Table 1). Averaged over the years, yield response to this application rate (30 kg/ha) was to the tune of 30% and 35% over no-S application rates at Garh Meerakpur and Jalalpur I, respectively. Earlier studies indicated that cereals have a lower S requirement (10-30 kg/ha) than many other agricultural crops, yet an 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 (Withers *et al.* 1995, Gill and Singh 2009). Significantly (P <0.05) large yield responses of rice to S fertilizer observed in the on-farm experiments at both the sites indicate that, despite their relatively low S requirement, the productivity of these staple foodgrains may be drastically reduced by an inadequate supply of S.

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 ascribed that balanced nutrition of NPK along with S restricted luxuriant crop foliage growth and converted more photosynthates towards economic yield. The higher grain S uptake recorded in the study may be visualized in this regard (Table 2). Differential response of rice to applied S particularly at 15 and 30 kg S rate, i.e. provided larger yield and improved agronomic use efficiency at Jalalpur I as compared to Garh Meerakpur (Table 1) which is associated with the difference in initial S content of the soil, that was distinctly greater (6.8 mg/kg) at Garh Meerakpur. 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).

Table 1 Direct effect of sulphur application on rice and residual wheat productivity at experimental sites of Trans-Gangetic Plain zone

Treatment	1st year	2nd year	3rd year	Pooled	Harvest index	Agronomic S use efficiency (kg grain/ kg S)
Rice yield (kg/ha)						
Garh Meerakpur						
NPK	4241	3543	3344	3709	42.4	
NPK S_{15}	4734	4280	4134	4383	44.1	44.9
NPK S_{30}	5160	4941	4383	4828	44.8	37.3
NPK S_{45}	5242	5102	4822	5055	46.2	29.9
CD (P=0.05)	472	330	413	439	1.4	8.1
Jalalpur I						
NPK	3683	3224	3181	3363	42.4	
NPK S_{15}	4394	3973	3792	4053	44.6	46.0
NPK S_{30}	4670	4642	4283	4532	45.9	39.0
NPK S_{45}	4731	4720	4424	4625	46.4	28.0
CD (P=0.05)	393	314	314	363	1.1	8.8
Residual wheat (kg/ha)						
Garh Meerakpur						
NPK	3968	3642	3552	3721	42.2	
NPK S_{15}	4286	3914	3880	4027	41.8	20.4
NPK S_{30}	4685	4463	4321	4490	44.2	25.6
NPK S_{45}	4884	4705	4824	4804	44.3	24.1
CD (P=0.05)	549	408	414	482	2.0	2.5
Jalalpur I						
NPK	3552	3280	3061	3298		
NPK S_{15}	3836	3511	3468	3605	9.3	20.5
NPK S_{30}	4021	3924	3847	3931	19.2	21.1
NPK S_{45}	4349	4435	4376	4387	33.0	24.2
CD (P=0.05)	588	410	399	504	1.2	2.8

Residual effect on wheat

Application of S at 30 or 45 kg/ha to rice brought significant 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, 0.92, 1.06 and 1.27 tonnes/ha increase in wheat yield was recorded with highest rate of S application at Garh Meerakpur during first, second and third year, respectively. Similar yield gain with 45 kg S/ha application was of 0.80, 1.16 and 1.32 tonnes/ha, respectively at Jalalpur I (Table 1). Averaged over the years, use of 30 kg and 45 kg S /ha produced 13 to 29% and 19 to 33% more yield over no-S (Control) at these locations. But the residual responses in wheat were not significant, 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 in available form of the soil even after harvest of directly fertilized rice crop (Biswas and Tewatia 1991, Tiwari *et al.* 2006). Increase in soil S content after wheat harvest in 30 or 45 kg /ha S-treated plots at both the sites support this contention (Table 3). A marked residual effect of S application was also noticed on harvest index of wheat crop when it was applied more than 30 kg/ha to previous rice crop. Contrary to rice, S use efficiency in residual wheat (kg grain/kg S) increased with increasing S rates except Garh Meerakpur where S use efficiency was declined beyond 30 kg application rates. These results inferred that (i) soil with relatively low S status produced higher residual response, and (ii) low rates of S fertilization in rice failed to leave sufficient S residue to be translated into agronomic yield in the succeeding wheat crop.

Effect on S uptake and fertilizer S recovery

Total S uptake of the RW system ranged between 68.1 to 136.1 kg/ha and 61.5 to 125.4 kg/ha at Garh Meerakpur and

Table 2 Total S uptake from 03 RW cycle at experimental site of Trans Gangetic Plain zone

Treatment*	S uptake in rice (kg/ha)$			S uptake in wheat (kg/ha)$			System S uptake (kg/ha)$	Recovery efficiency of S (%)
	Grain	Straw	Total	Grain	Straw	Total		
Garh meerakpur								
NPK	10.5	12.1	22.6	21.0	24.5	45.5	68.1	
NPK S_{15}	17.5	17.9	35.4	28.6	33.3	62.0	97.3	65.1
NPK S_{30}	23.6	22.0	45.6	36.8	37.9	74.7	120.3	57.9
NPK S_{45}	29.9	21.8	51.7	41.7	42.7	84.4	136.1	50.4
CD (P=0.05)	3.1	1.6	4.7	4.7	4.2	6.8	12.6	7.3
Jalalpur I								
NPK	8.8	10.5	19.3	20.6	21.6	42.2	61.5	
NPK S_{15}	15.7	12.6	28.3	28.5	27.2	55.7	84.0	50.0
NPK S_{30}	24.4	18.2	42.6	34.0	33.2	67.2	109.8	53.7
NPK S_{45}	27.2	21.8	49.0	39.0	37.4	76.4	125.4	47.3
CD (P=0.05)	2.6	2.2	5.7	4.8	4.8	8.3	16.5	6.8

$, S uptake during 03 years; *, total S applied during 3 years were 45 kg, 90 kg and 135 kg S/ha, respectively.

Table 3 Annual change in available soil S content (kg/ha) due to S fertilization under RW system at on-farm experimental sites of Trans-Gangetic Plain zone

Treatment	Initial status	After 1st year	After 2nd year	After 3rd year	% change over initial status: After 1st year	After 2nd year	After 3rd year
				Garh Meerakpur			
NPK	6.8	5.6	4.8	4.8	(–) 21	(–) 42	(–) 42
NPK S_{15}	6.8	5.8	5.0	5.2	(–) 17	(–) 36	(–) 31
NPK S_{30}	6.8	7.2	8.8	9.6	(+) 6	(+) 23	(+) 29
NPK S_{45}	6.8	8.9	10.6	11.8	(+) 24	(+) 36	(+) 42
CD (P=0.05)		0.8	1.1	1.6			
				Jalalpur I			
NPK	4.9	4.2	3.8	4.0	(–)17	(–) 29	(–) 23
NPK S_{15}	4.9	4.5	4.4	4.8	(–) 9	(–) 11	(–) 2
NPK S_{30}	4.9	5.1	6.2	8.0	(+) 4	(+) 21	(+) 39
NPK S_{45}	4.9	7	9.2	9.8	(+) 30	(+) 47	(+) 50
CD (P=0.05)		1.3	1.7	0.7			

Jalalpur I, respectively during 03 crop cycle. 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 by 129% and 154% in rice and 86% and 81% in wheat at Garh Meerakpur and Jalapur I, 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) at both the locations (Table 2). The recovery efficiency (RE, %) of S declined with increasing S rates at Garh Meerakpur, while it was increased up to 30 kg S/ha application rate and thereafter declined at Jalalpur I. The increasing REs up to 30 kg S rates at Jalalpur I may be corroborated with the comparatively smaller initial soil S status of the site which exhibited higher S response and uptake.

Effect of S application on available S status of the soil

At the onset of the experiment, available S status of the experimental site at Garh Meerakpur and Jalalpur I was 6.8 and 4.9 mg/kg, respectively. A gradual increase in soil S status was noticed over the years in 30 or 45 kg/ha S applied plots. Application of 45 kg S/ha to rice, during three rice-wheat cropping season, however, raised the S status up to 11.8 mg/kg (Garh Meerakpur) and 9.8 mg/kg (Jalalpur I) at third wheat harvest (Table 3). S application at 30 kg/ha resulted in buildup of available S status to the tune of 29 to 50%. On the other hand, a decline in soil S status over initial S content (2 to 31%) was noticed at these sites with 15 kg/ ha S application. These results are in close conformity with the earlier studies by Singh 2001, Singh and Mishra 2010, wherein increase in soil S status with addition of S in optimal quantity had positive effect on available soil S pool.

Apparent S balance sheet

During the 3 years of experimentation, S addition through fertilizer, residue and irrigation water were in the range of 30.2 to 172 kg/ha and 25 to 166.3 kg/ha at Garh Meerakpur and Jalalpur I, respectively. Apparent balance sheet, computed as sulphur addition from different sources less sulphur off-take in the crops, revealed positive S balance under 30 and 45 kg/ha S applied plots at Garh Meerakpur and all rates of S application at Jalalpur I sites. On the other hand, S balances were negative under S skipped plots at both the locations and also with 15 kg/ha S application at Garh Meerakpur. The negative S balance under 15 kg S applied plot at Garh Meerakpur site may be explained in terms of increased total S uptake under no-S (control) plot (Table 2) indicating comparatively higher native soil S supply which was not included during computation of balance sheet. Further, negative S balance under no-S plots at both the sites indicates the possible depletion of sulphur from soil reserves when its application is omitted. A gradual decline in soil S content over the years under no-S (Control) or 15 kg S applied plots

Table 4 Apparent S balance sheet under RW system at experimental sites of Trans Gangetic Plain zone

S rate (kg/ha)	Total S input in 3 years (kg/ha): Fertilizer	Residue	Irrigation	Total S (kg/ha)	Total S uptake (kg/ha)	Balance (kg/ha)
Garh Meerakpur						
S_0	0	6.8	23.4	30.2	68.6	(–) 38.4
S_{15}	45	9.7	23.4	78.1	97.0	(–) 18.9
S_{30}	90	12.0	23.4	125.4	120	(+) 5.4
S_{45}	135	13.6	23.4	172.0	136	(+) 36.0
Jalalpur I						
S_0	0	4.8	20.7	25	47.6	(–) 22.6
S_{15}	45	6.5	20.7	72.2	65.3	(+) 6.9
S_{30}	90	9.0	20.7	119.7	90.6	(+) 29.1
S_{45}	135	10.6	20.7	166.3	106.1	(+) 60.2

Table 5 Value cost ratio (VCR) of sulphur fertilization for rice- wheat cropping system at experimental sites of TGP

Treatment	VCR (₹ return/₹ invested)											
	Direct on 1st crop				Residual on 2nd crop				Total on both crops			
	1st year	2nd year	3rd year	Mean	1st year	2nd year	3rd year	Mean	1st year	2nd year	3rd year	Mean
Garh Meerakpur												
NPK												
NPK S_{15}	53.8	66.7	77.6	66.1	46.0	40.9	45.8	44.2	99.8	107.6	123.4	110.3
NPK S_{30}	48.1	64.4	53.2	55.2	46.4	51.9	45.2	47.2	94.5	116.3	98.4	103.1
NPK S_{45}	28.5	48.0	47.5	41.3	40.4	46.4	52.0	46.2	68.9	94.4	99.5	87.6
Jalalpur I												
NPK												
NPK S_{15}	73.4	68.2	59.0	66.8	36.3	30.5	47.3	38.0	109.7	98.7	106.3	104.9
NPK S_{30}	51.9	64.1	53.3	56.4	31.4	40.9	44.7	39.0	83.3	105.0	98	95.4
NPK S_{45}	36.1	45.4	39.9	40.4	33.8	46.8	52.8	44.5	69.9	92.2	92.7	84.9

(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 even when a nutrient is not applied and leads to decline in native nutrient supplying capacity.

Economics of S application

The value cost ratio (VCR) of rice due to S application ranged between 28.5 to 77.6 at Garh Meerakpur and 36.1 to 73.4 at Jalalpur I in different years (Table 5). Averaged over the years, it decreased with increasing S rates and maximum being at 15 kg S application rates (66 and 67 at Garh Meerakpur and Jalalpur I, 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 rate at Garh Meerakpur and upto highest level of S application rate at Jalalpur I, which may be ascribed in terms of lower initial soil S status at the Jalalpur I site resulting higher yield response and economics even at 45 kg/ha S application rate. Averaged across the years, VCR for RW system was maximum at 15 kg S application rates (103 to 95 Return (₹) /₹ invested in S), which declined with increasing S application rate.

Impact of farmers participatory S management studies

At the onset of the study (2003-04) 69% farmers were using N and P as fertilizer nutrient in RW system with annual productivity of 7.82 t/ha (Fig 2). Use of S to rice-wheat system was only in 17% farmers' field and out of this, 11% farmers applied S along with N and P and 6% applied S with NPK fertilizer nutrients. The Nutrient consumption ratio for N: P: S and N: P: K: S was 39.1:11.8:10 and 36.4:12.9:3.9:1, respectively. At these nutrient consumption ratios, average annual RW system productivity was of 9.18 and 10.38 tonnes/ha, respectively. Technological interventions made during 2003-2006 through on-farm experimentation, field days and

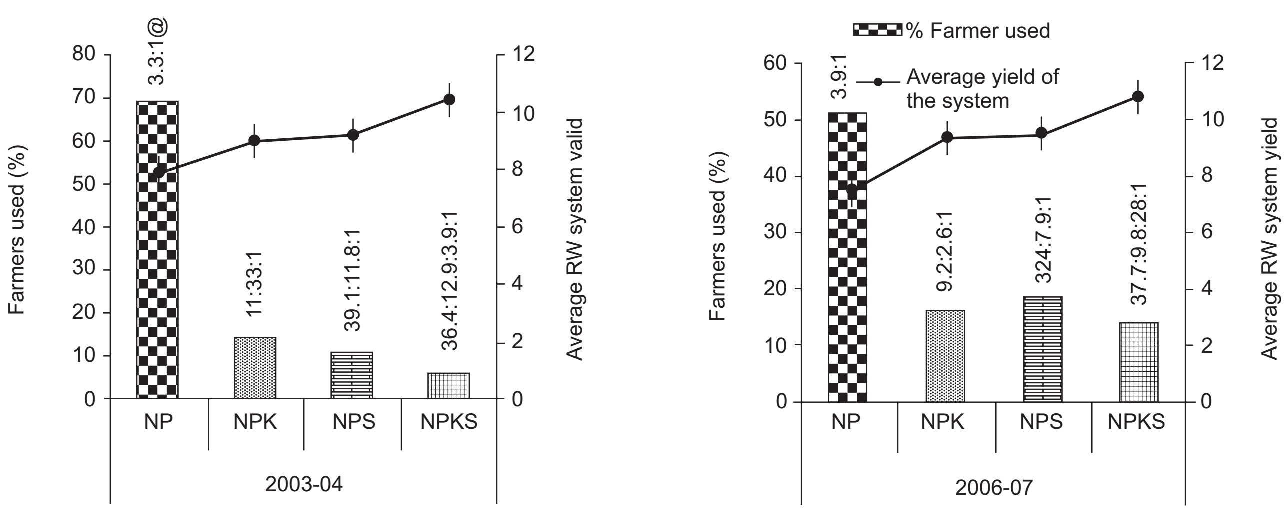

Fig 2 Impact of farmer's participatory S management program on nutrient use pattern and rice-wheat cropping system productivity in surveyed area @ nutrient consumption ratio. Bar indicates standard error.

farmers participatory sulphur promotion programmes had a marked impact on nutrient use pattern and 33% surveyed farmers started using S to their fertilization schedule for rice-wheat system by 2007. Inclusion of S to fertilization schedule had pronounced effect on enhancing the average RW system productivity (16 to 26%) over NP or NPK alone and also on narrowing NPS and NPKS ratio (Fig 2). The increasing S use and its impact on higher system productivity may be credited to increased awareness among the farmers regarding rate, time and method of S application, timely availability of quality S containing fertilizer and perceived knowledge by seeing and believing process about S role in plant growth and development. Further, these results amply unveil the necessity of inclusion of S in fertilization schedule for enhancing RW system productivity and sustained soil health.

Foregoing results revealed that the soils of rice-wheat growing areas of TGP suffer from varying degree of S deficiency and the magnitude is larger in the soils containing low OC content. Substantial direct and residual responses to S fertilizer in rice-wheat system under on-farm studies and farmers participatory surveys indicates that skipping S from fertilization schedule may have adverse effect not only on yield and profit but also on soil sustainability.

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