Potassium, Sulphur and Zinc Application Improved Yield and Economics of Rice-Wheat Systems

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On-farm experiments conducted at 60 locations in northern India demonstrated that yields and profits for rice and wheat increased significantly with a combined application of K, S and Zn along with farmer fertilisation practice that primarily focuses on N and P application. Application of Zn improved grain Zn contents in rice and wheat, which is critical for nutritional security in the region. Soil exchangeable and non-exchangeable K decreased without K application and increased with K application within just one rice-wheat cropping cycle.

Caption: Zinc deficiency in rice (left) and **S deficiency in wheat** (right). Zinc deficiency is seen as yellow and brown necrotic patches gradually extending outwards towards the tip and base of the leaf; while S deficiency is seen as general leaf yellowing with young leaf tips eventually becoming necrotic.

Fertiliser use in the rice-wheat systems (RWS) of Indo-Gangetic Plains (IGP) is highly variable. Generally, the nutrient application rates do not match the nutrient removal rates from the soils, leading to declining crop yields and factor productivity in the RWS (Singh et al., 2005). On-farm farmers' participatory surveys showed that farmers typically applied ample N (78 to 150 kg N/ha) and P (13 to 25 kg P/ha) to rice, and 82 to 196 kg N/ha and 15 to 33 kg P/ha to wheat, while largely ignoring application of other nutrients, particularly K (Singh et al., 2013). This is because farmers are either unaware of the benefits of other nutrients or lack access to those fertilisers during periods of peak demand. All this is leading to increasing concerns on the productivity of RWS and soil fertility status in the IGP. For example, Bijay-Singh et al. (2003) and Yadvinder-Singh et al. (2005) observed that soil K reserves are being depleted to levels insufficient to sustain high yields. Similarly, Shukla and Behra (2011) indicated that S and micronutrient deficiencies are emerging as significant limitations to the productivity of RWS. We conducted on-farm experiments with rice and wheat crops in northern India to: 1) determine the responses of rice and wheat to fertiliser K, S and Zn applications, 2) assess financial returns associated with their application, and 3) evaluate soil K balances.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc.

About 60 famers' fields were chosen in Punjab (Fatehgarh Sahib district), Uttar Pradesh (Meerut, Banda and Barabanki districts) and Bihar (Bhagalpur district) states to conduct the experiments in 2005-06. Fatehgarh Sahib, Meerut, Barabanki, and Bhagalpur districts are located in the IGP, while Banda district, which is located outside the IGP, has RWS as an emerging crop production system. All locations had four fertiliser treatments, viz., farmer's fertiliser practice (FFP), FFP + K (+K), FFP + K + S + Zn (+KM), and FFP + S + Zn (+M). In the +K and +KM plots, K was applied using muriate of potash at 63 kg K/ha to rice as well as wheat. In rice, K was applied as 50% basal and 50% at 50 days after transplanting, whereas in wheat, all K was applied as basal. Sulphur was applied as basal using elemental S powder (80% S) at 30 kg S/ha to both rice and wheat, while Zn was applied only to the rice crop as zinc sulfate (21% Zn) at 5 kg Zn/ha. The existing farmer's fertiliser practice that only includes the applications of fertiliser N and P was followed in all four treatments for rice and wheat. The +M treatment with applied S and Zn was treated as the equivalent of a K-omission plot allowing assessment of the K-limited yield because farmers typically apply sufficient fertiliser N and P but no fertiliser K to their fields (Singh et al., 2013). The treatment with applied K served as an omission plot for S plus Zn capable of assessing soil indigenous S and Zn supply based on the yields of rice and wheat. However, it was not possible to ascertain from this study whether the yield

Table 1. Effect of potassium and sulphur plus Zn (M) additions in rice and rice-wheat system (SREY) at five locations in northern India.

	Fatehgarh Sahib			Meerut			Banda			Barabanki			Bhagalpur		
Parameter	No M	+M	Diff†	No M	+M	Diff	No M	+M	Diff	No M	+M	Diff	No M	+M	Diff
Rice grain yield (t/ha)															
No K	5.9	6.6	0.7**	4.9	5.5	0.6***	2.7	3.3	0.6***	5.0	5.4	0.4***	3.5	4.3	0.9***
+K	6.5	7.0	0.5*	5.7	6.1	0.4***	3.7	4.1	0.4***	5.6	5.9	0.3***	4.6	4.9	0.2***
Difference‡	0.6***	0.4*		0.9***	0.6***		1.0***	0.7***		0.6***	0.5***		1.2***	0.5***	
Rice grains per panicle (no.)															
No K	91	97	6ns	64	69	5***	97	105	8***	108	110	3**	81	86	5***
+K	98	104	6**	69	72	3***	118	128	10***	112	115	3***	88	90	1***
Difference	7**	7*		5**	3***		22***	23***		5***	5***		8***	4***	
Total K in rice (kg/ha)															
No K	108	122	14**	102	114	12***	56	66	11***	98	101	3ns	74	90	16***
+K	130	140	10**	130	137	7***	80	87	7***	119	127	8***	103	109	6***
Difference	23***	18***		27***	22***		24***	21***		21***	26***		29***	20***	
Wheat grains per spike (no.)															
No K	44	46	2.5***	40	44	4.4***	41	43	1.6***	38	39	1.6***	39	42	3.0***
+K	46	49	3.2***	46	48	2.2***	43	46	2.7***	40	41	1.4**	45	47	2.5***
Difference	1.7***	2.4***		6.0***	3.8***		2.0***	3.1***		2.2***	2.0***		5.3***	4.8***	
Rice equivalent yield for system (SREY) (t/ha)															
No K	11.7	12.6	0.9***	10.0	11.2	1.2***	5.7	6.8	1.0***	9.5	10.3	0.7***	6.4	7.7	1.3***
+K	12.5	13.2	0.7**	11.8	12.6	0.8***	7.2	8.0	0.8***	10.6	11.2	0.6***	8.4	9.1	0.7***
Difference	0.8***	0.6**		1.8***	1.4***		1.5***	1.3***		1.1***	0.9***		2.1***	1.4***	

† Diff = Difference between non-rounded treatment means for no added S + Zn (no M) and added S + Zn (+M).
‡ Difference = Difference between non-rounded treatment means for no added K (no K) and added K (+K).
ns = Not significant at $p \leq 0.05$, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, and *** = Significant at $p \leq 0.001$.
The K×M×location interaction was significant at $p \leq 0.05$ for all listed parameters.

gains from S + Zn arose from added S, Zn, or both S and Zn.

Twenty-five day old seedlings of rice (cv. PHB 71) were transplanted during June-August in farmers' fields. At maturity, rice was harvested manually, the land was tilled three to four times, and the succeeding wheat crop (cv. PBW 343) was sown on the same plots during November-December. Grain and straw yields of rice and wheat were determined from a 10 m^2 area in each plot, comprised of four predetermined 2.5 m^2 harvest areas. Rice and wheat grain yields were reported at 14% moisture content. Soil samples were collected at 0 to 15 cm depth before the start of the experiment and after wheat harvest. Soils were analysed for extractable N, extractable P, exchangeable K, non-exchangeable K, extractable S, and DTPA-extractable Zn using standard analytical procedures. Means for the initial soil properties for each district are reported elsewhere (Singh et al., 2013). Representative subsamples of grain and straw of rice and wheat crops were analysed for total K, S and Zn.

Added net return for fertilisation with K, S and Zn relative to FFP was determined using prices for rice grain (₹8.55/kg), rice straw (₹0.5/kg), wheat grain (₹10.35/kg), wheat straw (₹2.75/kg), fertiliser N (₹10.35/kg), fertiliser P (₹16.2/kg), fertiliser K (₹9.0/kg), fertiliser S (₹11.7/kg) and fertiliser Zn (₹30.15/kg). Comparisons of yield for the locations were made on rice equivalent yield for systems (SREY):

$$SREY = Y_R + [(YW \times PW) / PR]$$

where, Y_R = rice grain yield in kg/ha, Y_W = wheat grain yield in kg/ha, P_R = price of rice in ₹/kg, and P_W = price of wheat in ₹/kg. All data were analysed using SAS (version 9.1.2).

Crop Response to Potassium, Sulphur and Zinc Application

Rice yield in FFP plots ranged from 2.7 t/ha at Banda to 5.9 t/ha at Fatehgarh Sahib. Application of K increased rice grain yields ($p \leq 0.001$) at all locations (**Table 1**) regardless of the large differences in soil textures as well as soil exchangeable and non-exchangeable K statuses among farms (Singh et al., 2013). For example, K application increased rice yields by 0.6 t/ha in Fatehgarh Sahib and Barabanki, 0.9 t/ha in Meerut, 1 t/ha in Banda, and 1.2 t/ha in Bhagalpur. Similarly, the yield increases from applied K in the presence of S and Zn (+M) ranged from 0.4 to 0.7 t/ha across all locations. The significant increase in rice yields due to K application is in stark contrast to the popular belief that K status of the IGP soils is sufficient to meet the K needs of crops (Bijay-Singh et al., 2003), but is consistent with recent scientific reports that clearly indicate that the application of K has become essential for sustaining high yields in the IGP (Regmi et al., 2002). This increase in rice yields due to K application was associated with increased number of grains per panicle (**Table 1**) and a reduced percentage of unfilled grains (**Table 2**). Application of K increased total plant K at maturity ($p \leq 0.001$) by 21 to 29 kg/ha across the five locations (**Table 1**), while the increase in total plant S ranged from 1.3 to 2.8 kg/ha (**Table 2**).

Highest yield of rice was obtained when K was applied with S + Zn (**Table 1**). Application of K, S and Zn with FFP increased rice grain yields by 1.1 t/ha at Fatehgarh Sahib, 1.2 t/ha at Meerut, 1.4 t/ha at Banda, 0.9 t/ha at Barabanki, and 1.4 t/ha at Bhagalpur vis-à-vis FFP alone. Singh et al. (2008)

Table 2. Effect of potassium and sulphur plus zinc (M) application on grain filling and uptake of nutrients by rice and grain yield and the uptake of nutrients for wheat at five locations in northern India.

Parameter	Fatehgarh Sahib	Meerut	Banda	Barabanki	Bhagalpur
Rice unfilled grain (%)					
No K	12	10	11	10	12
+K	10	6	5	8	10
Difference†	-1.8ns	-4.5***	-5.4***	-1.3*	-2.7***
No M	12	9	9	10	11
+M	9	7	7	9	11
Difference‡	-2.9***	-2.3***	-1.7**	-1.0ns	-1.0ns
Total S in rice (kg/ha)					
No K	24	23	12	20	15
+K	26	25	15	22	17
Difference	1.3***	2.2***	2.8***	1.7**	2.4***
No M	20	20	10	16	12
+M	30	28	17	25	21
Difference	10.8***	8.4***	7.4***	9.1***	9.3***
Rice grain zinc (mg/kg)					
No K	32	32	34	31	33
+K	32	32	34	32	34
Difference	0.2ns	0.2ns	0.0ns	0.7*	0.9**
No M	29	30	30	28	30
+M	35	35	38	34	37
Difference	6.3***	5.2***	7.3***	6.0***	6.3***
Wheat grain yield (t/ha)					
No K	4.6	4.3	2.5	3.7	2.5
+K	4.8	5.0	2.9	4.1	3.2
Difference	0.2***	0.7***	0.4***	0.3***	0.7***
No M	4.6	4.4	2.6	3.8	2.6
+M	4.8	4.8	2.9	4.0	3.0
Difference	0.2***	0.4***	0.3***	0.3***	0.4***
Total K in wheat (kg/ha)					
No K	101	80	51	74	50
+K	114	99	64	93	68
Difference	13.8***	18.7***	13.3***	19.8***	17.8***
No M	108	86	55	81	56
+M	107	93	60	86	62
Difference	-0.1ns	7.5***	5.8***	4.1**	6.4***
Total S in wheat (kg/ha)					
No K	25	23	13	18	13
+K	26	27	14	20	16
Difference	0.4*	3.7***	1.8***	1.9***	3.7***
No M	20	20	10	15	11
+M	31	29	17	24	18
Difference	11.4***	9.0***	6.9***	9.8***	6.7***
Wheat grain zinc (mg/kg)					
No K	30	31	33	30	32
+K	30	31	33	30	33
Difference	0.5ns	0.4ns	0.3ns	-0.1ns	0.3ns
No M	27	29	29	26	29
+M	33	34	37	34	36
Difference	5.7***	5.0***	7.8***	7.4***	6.8***

† Difference between non-rounded means for two no K treatments (no application of K, S or Zn and application of S + Zn) and two +K treatments (application of K only and application of K with S + Zn).
‡ Difference between non-rounded means for two no M treatments (no application of K, S or Zn and application of K only) and two +M treatments (application of S + Zn only and application of K with S + Zn).
ns = Not significant at $p \leq 0.05$, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, and *** = Significant at $p \leq 0.001$.
The K×M×location interaction was not significant at $p \leq 0.05$ for all the listed parameters.

observed K, S and Zn deficiencies for rice in on-station and researcher-managed trials in the IGP and also documented the benefits of K, S and Zn in farmers' fields across the IGP from Punjab to Bihar.

Application of S plus Zn (+M) with and without the application of K increased rice yields by 0.2 to 0.9 t/ha across the experimental locations (**Table 1**). Like with K application, the increase in rice yield due to S + Zn application was associated with increased number of grains per panicle and a reduced percentage of unfilled grains. Shukla and Behra (2001) indicated widespread deficiencies of S and Zn in Indian soils. Application of S + Zn significantly ($p \leq 0.001$) increased the total plant S content by 7.4 to 10.8 kg/ha and the total plant Zn content by 76 to 103 g/ha at maturity across the five locations. This increase in plant Zn corresponded to significant increases ($p \leq 0.001$) in Zn concentrations by 5.2 to 7.3 mg/kg in un-milled rice grain across the five locations. This indicated that a balanced application of Zn can help in increasing yields and the nutritional quality of rice.

Wheat yield with FFP ranged from 4.5 t/ha at Fatehgarh Sahib to 2.3 t/ha at Banda and Bhagalpur (Singh et al., 2013). Application of 63 kg K/ha to wheat following the similar application to rice significantly increased ($p \leq 0.001$) wheat yield by 0.2 t/ha at Fatehgarh Sahib, 0.7 t/ha at Meerut and Bhagalpur, 0.4 t/ha at Banda and 0.3 t/ha at Barabanki (**Table 2**). The increase in wheat yield due to K fertilisation was associated with increased number of wheat grains per spike (2 to 6) at all locations (**Table 1**).

Application of S + Zn to the preceding rice crop and then the application of 30 kg S/ha to wheat crop (+M) significantly increased ($p \leq 0.001$) wheat yields by 0.2 t/ha at Fatehgarh Sahib, 0.4 t/ha at Meerut and Bhagalpur and 0.3 t/ha at Banda and Barabanki (**Table 2**). Like with rice, the application of S to wheat significantly increased the total S content in the wheat plant at maturity by 6.7 to 11 kg/ha. However, the increase in plant Zn content in wheat crop at maturity corresponded to increases ($p \leq 0.001$) in Zn concentration of 5.0 to 7.8 mg/kg in un-milled wheat grain across the five locations despite no Zn application in wheat. This indicated that the residual effect of Zn applied to rice can be sufficient to increase Zn content in grains of the subsequent wheat crop.

System Performance and Financial Returns

The productivity of the RWS measured in terms of rice equivalent yield for the system (SREY) increased significantly with the application of either K or S+Zn at all locations (**Table**

Table 3. Effect of potassium and sulphur plus zinc (M) application on added net return for rice and wheat relative to the farmer's fertiliser practice without added K or M in a rice-wheat system at five locations in northern India.

		Added net return from added nutrients				
		Fatehgarh Sahib	Meerut	Banda	Barabanki	Bhagalpur
Crop	Treatment	- - - - - - - -	- - - - -	₹/ha	- - - - -	- - - - - - - -
Rice	+K	5,355a	7,830b	8,595b	5,130b	10,485b
Rice	+KM	9,765a	11,160a	12,015a	7,875a	12,645a
Rice	+M	6,075a	5,670c	5,400c	3,240c	7,740c
Wheat	+K	1,305b	9,540b	5,175b	4,545b	9,630b
Wheat	+KM	2,655a	13,995a	9,630a	7,875a	14,400a
Wheat	+M	1,710ab	6,030c	4,500c	3,330c	4,950c

Means within a column for a crop followed by the same letter are not significantly different according to Tukey-Kramer test at $\alpha = 0.05$.

1). Application of K increased SREY by 0.6 to 2.1 t/ha, while the application of S+Zn increased SREY by 0.6 to 1.3 t/ha. Combined application of the three nutrients (K, S and Zn) increased SREY from 1.5 t/ha in Fatehgarh Sahib to 2.7 t/ha in Bhagalpur.

Added net return from applied K and S+Zn was positive for rice and wheat at all locations (**Table 3**). Added net return for rice was lowest with the application of only S+Zn (without K) and highest with the application of K+ S + Zn across all locations, except for Fatehgarh Sahib. Similarly, the added net return in wheat was highest with the application of K with S+Zn across all locations, except Fatehgarh Sahib. Added net return for wheat was greater from the application of only K than only S+Zn at all locations, except Fatehgarh Sahib and Banda. Although yields and yield gains from added nutrients tended to be lower for wheat than rice, the added net return remained high for wheat due to higher values of grain and straw for wheat than for rice and lower fertilisation costs in wheat because zinc was not applied to wheat.

Changes in Soil K Status

In the absence of added K, exchangeable K decreased by 6 to 9 mg/kg and non-exchangeable K decreased by 18 to 30 mg/kg during one rice-wheat cropping cycle (**Table 4**). With K application, exchangeable K increased by 6 to 9 mg/kg and non-exchangeable K increased by 7 to 14 mg/kg. The differences between application of K with FFP and FFP after one rice-wheat cropping cycle ranged from 13 to 18 mg/kg for exchangeable K and 26 to 41 mg/kg for non-exchangeable K across all locations. The decline in soil K without added K highlights the risk of rapid short-term mining of soil K with the farmer's current fertilisation practice of using relatively high rates of N and P with little or no use of K. Long-term cropping with negative K balances has been associated with yield declines in the RWS in South Asia (Bijay-Singh et al., 2003). Although the K-supplying capacity of illite-dominated alluvial soils of the IGP is relatively high, long-term intensive cropping with inadequate application of K can result in K mining leading to large negative balances and depletion of native K reserves (Yadvinder-Singh et al., 2005).

Table 4. Change in soil potassium during one cycle of rice-wheat cropping at five locations in northern India.

Parameter	Fatehgarh Sahib	Meerut	Banda	Barabanki	Bhagalpur
Change in exchangeable K (mg/kg)					
No K	-6	-6	-7	-8	-9
+K	6	7	7	8	9
Difference†	13***	13***	14***	17***	18***
Change in non-exchangeable K (mg/kg)					
No K	-30	-22	-19	-26	-18
+K	11	9	7**	14	14
Difference	41***	31***	26***	40***	33**

† Difference between non-rounded means for two no K treatments (no application of K, S or Zn and application of S + Zn) and two +K treatments (application of K only and application of K with S + Zn).
ns = Not significant at $p \leq 0.05$, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, and *** = Significant at $p \leq 0.001$.
The K×M×location interaction was not significant at $p \leq 0.05$ for all the listed parameters.

Summary

Widespread deficiencies of K, S and Zn in the soils of the IGP due to imbalanced and inadequate application of these nutrients have become major constraints for sustained productivity of the RWS. The results of our on-farm experiments distributed across contrasting locations and fields in the IGP established the importance of sufficient use of K, S and Zn along with N and P to match crop needs. Our study clearly showed that the use of K with S+Zn can increase crop yields and productivity of the RWS and provide attractive net economic benefits to farmers. Application of Zn improved grain Zn contents in rice and wheat, which is critical for nutritional security in the region. BC-SA

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