Economic Viability of Site-Specific Nutrient Management in Rice-Wheat Cropping

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The most dominant rice-wheat system of India is showing signs of fatigue, mainly due to inadequate and unbalanced fertilisation. The current productivity can be doubled by growing hybrid rice and locally recommended high-yielding varieties of wheat and by increasing balanced fertiliser application rates to correct multiple nutrient deficiencies which are being widely observed.

The rice-wheat cropping system (RWCS) is the most widely adopted system, covering over 10.5 M ha—mostly in northwest zone (Paroda et al., 1994). The productivity of both rice and wheat is low…2,130 and 2,670 kg/ha, respectively, mainly due to poor soil fertility, inadequate, unbalanced, and inefficient use of fertilisers (Yadav et al., 2000; Dwivedi et al., 2001). Continuous rice-wheat cropping without adequate and balanced nutrition has resulted in a widespread problem of multiple nutrient deficiencies (Timsina and Connor, 2001). A multi-location, on-station research was initiated to evaluate the significance of site specific nutrient management (SSNM) towards breaking yield stagnation. The research considers all existing nutrient deficiencies and correcting them so as meet nutrient requirements of high yield goals.

Field experiments were conducted for 3 years during to 2003-04 to 2005-06 to evaluate the effect of SSNM in rice-wheat cropping systems at 9 locations representing intensive agriculture in northwest India. The deep alluvial soils of the experimental sites were generally sandy loam to loamy sand, but were clayey at Faizabad and Varanasi. Most sites had neutral to slightly alkaline soils (pH 6.0 to 8.2), but were acidic (pH 5.2) at Palampur. Soils were low to medium in available N, K, S, B, and Mn and medium to high in available P and Zn. The initial soil analysis was done by Agro-International, U.S.A. as per methods described by Portch and Hunter (2002). These soil analyses were the basis for developing SSNM recommendations for yield targets of 10 t/ha of hybrid rice and 6 t/ha of wheat.

While SSNM treatments required more investment in fertiliser nutrients, net returns were very favorable.

Selected treatments allowed the assessment of responses to all the deficient nutrients so as to develop viable fertiliser best management practices (BMPs) for high yield sustainable agriculture. The SSNM nutrient packages for each site included all macro, secondary, and micronutrients considered deficient (**Table 1**). Both crops received NPK, while S and micronutrients were applied to rice only. The efficacy of SSNM was compared against a state fertiliser recommendation (SR) and farmers' fertiliser practice (FP). Omission plots for different

Table 1. Experimental location and the nutrient applied in the rice-wheat cropping system.

		Nutrient applied, kg/ha					
		Rice			Wheat		
Location	State	SSNM	SR	FP	SSNM	SR	FP
Sabour	Bihar	$N_{150}P_{30}K_{100}S_{40}$	$N_{100}P_{40}K_{40}$	$N_{60}P_{30}$	$N_{150}P_{30}K_{100}$	$N_{120}P_{60}K_{40}$	$N_{60}P_{30}$
Palampur	Himachal Pradesh	$N_{100}P_{25}K_{80}S_{40}Zn_{20}B_5$	$N_{100}P_{30}K_{30}$	$N_{80}P_{20}$	$N_{100}P_{25}K_{80}$	$N_{100}P_{30}K_{30}$	$N_{80}P_{20}$
Ranchi	Jharkhand	$N_{150}P_{60}K_{100}S_{25}Zn_{30}B_5$	$N_{150}P_{75}K_{60}$	$N_{80}P_{40}K_{20}$	$N_{150}P_{60}K_{100}$	$N_{150}P_{75}K_{60}$	$N_{80}P_{40}K_{20}$
R.S. Pura	Jammu & Kashmir	$N_{150}P_{100}K_{120}S_{50}Zn_{40}Mn_{20}$	$N_{120}P_{60}K_{30}$	$N_{50}P_{30}K_{20}$	$N_{150}P_{100}K_{120}$	$N_{120}P_{60}K_{30}$	$N_{50}P_{30}K_{20}$
Ludhiana	Punjab	$N_{150}P_{60}K_{150}S_{40}Zn_{25}B_5Mn_{20}$	$N_{120}P_{30}K_{30}Zn_{25}$	$N_{180}P_{60}Zn_{10}$	$N_{150}P_{60}K_{150}$	$N_{120}P_{30}K_{30}$	$N_{180}P_{30}$
Faizabad	Uttar Pradesh	$N_{150}P_{60}K_{120}S_{40}Zn_{25}B_5Mn_{20}$	$N_{120}P_{60}K_{60}$	$N_{90}P_{40}$	$N_{150}P_{60}K_{120}$	$N_{120}P_{60}K_{60}$	$N_{90}P_{40}$
Kanpur	Uttar Pradesh	$N_{150}P_{30}K_{120}S_{50}Zn_{40}$	$N_{150}P_{75}K_{60}S_{25}$	$N_{80}P_{30}$	$N_{150}P_{30}K_{120}$	$N_{150}P_{75}K_{60}$	$N_{80}P_{30}$
Modipuram	Uttar Pradesh	$N_{150}P_{30}K_{80}S_{20}Zn_{25}B_5Mn_{20}$	$N_{150}P_{75}K_{75}Zn_{25}$	$N_{180}P_{60}Zn_{25}$	$N_{150}P_{30}K_{80}$	$N_{120}P_{60}K_{40}$	$N_{180}P_{60}$
Varanasi	Uttar Pradesh	$N_{150}P_{30}K_{80}S_{40}Zn_{40}B_5Mn_{20}Cu_{20}$	$N_{150}P_{75}K_{75}Zn_{25}$	$N_{180}P_{60}Zn_{25}$	$N_{150}P_{30}K_{80}$	$N_{120}P_{60}K_{40}$	$N_{180}P_{60}$

The equal levels of P and K are in the form of P_2O_5 and K_2O, Zn, Mn, and Cu are in the form of sulfate and B as borax.

Abbreviations and notes for this article: N = nitrogen, P = phosphorus, K = potassium, S = sulphur, B = boron, Mn = manganese, Zn = zinc.

treatments were maintained to determine the individual responses to specific nutrient application.

Fertiliser sources included urea (46% N), diammonium phosphate (18% N and 46% P_2O_5), potassium chloride (60% K_2O), elemental S, zinc sulphate (21% Zn and 10% S), borax (10.5 % B), manganese sulphate (30.5% Mn, 17.5% S), and copper sulphate (24% Cu, 12% S). Entire quantities of P, K, S, and micronutrients, and one-third of the total N were applied at planting. The remaining N was top-dressed in two equal splits. Hybrid rice cv. PHB 71 and locally recommended high yielding varieties of wheat were grown at all locations.

Economic comparisons for each of the nutrient management options included analysis of gross and net returns, as well as the additional returns per unit investment in each individual crop and the entire RWCS. Agronomic efficiency and economic viability were assessed as well as apparent nutrient recovery on a individual crop and cropping system basis. Results reported here are averages of 3 years of study.

The mean grain yield of rice (unhusked) obtained with the SSNM was 8.20 t/ha as compared to 6.95 t/ha under the SR and 6.03 t/ha under FP (**Table 2**). SSNM out-yielded FP by 2.17 t/ha (+36%). The extra yield obtained with rice through SSNM (over FP) ranged from 1.0 t/ha at Varanasi to 3.27 t/ha at Sabour, indicating an almost three-fold difference among locations. This yield advantage with rice was of the order of 25% or more at 7 out of 9 sites. The SSNM treatment out-yielded FP by more than 2 t/ha at 5 out of 9 locations. Similarly, rice yields under SSNM were 3 t/ha or more than FP at Sabour, Faizabad, and Modipuram. Although SR had a significant edge over FP, the overall response was limited to only 0.92 t/ha (+15%).

Averaged over locations, the grain yield of the succeeding wheat crop was 4.86 t/ha with SSNM against 3.56 t/ha under FP (**Table 2**). Averaged across locations, the SSNM plot out-yielded FP by 1.30 t/ha (+41%). The additional yield obtained with SSNM over FP ranged from 391 kg/ha at Ludhiana to 1,924 kg/ha at Sabour indicating an almost five-fold difference among locations. This yield advantage was 30% or more at 6 out of 9 locations. Similarly, the productivity gain over FP was more than 1.0 t/ha at 7 out of 9 locations. As with rice, a significant yield response for SR was also obtained in wheat and the magnitude of yield increase over FP was 744 kg/ha (+21%).

Table 2. Grain yield response to SSNM and state recommended fertiliser doses over farmer nutrient management practice.

	Rice			Wheat			Rice-wheat system		
		Response			Response			Response	
Treatment	Yield, t/ha	t/ha	%	Yield, t/ha	t/ha	%	Yield, t/ha	t/ha	%
Sabour									
SSNM	8.23	3.27	66	5.18	1.92	59	13.40	5.19	63
SR	6.03	1.07	22	4.55	1.30	40	10.58	2.37	29
FP	4.96	–	–	3.25	–	–	8.21	–	–
Palampur									
SSNM	5.28	1.14	28	3.41	1.26	59	8.70	2.41	38
SR	4.70	5.58	14	2.99	0.84	39	7.68	1.39	22
FP	4.14	–	–	2.15	–	–	6.29	–	–
Ranchi									
SSNM	6.76	2.56	61	4.05	1.47	57	10.80	4.03	60
SR	5.96	1.76	42	3.40	0.82	32	9.36	2.58	38
FP	4.20	–	–	2.58	–	–	6.77	–	–
R.S. Pura									
SSNM	8.40	1.71	26	4.64	1.35	41	13.04	3.06	31
SR	7.38	0.69	10	4.07	0.78	24	11.46	1.47	15
FP	6.69	–	–	3.29	–	–	9.99	–	–
Ludhiana									
SSNM	10.43	1.30	14	6.02	0.39	7	16.45	1.69	11
SR	9.81	0.67	7	5.79	0.16	3	15.60	0.83	6
FP	9.13	–	–	5.63	–	–	14.77	–	–
Faizabad									
SSNM	8.28	3.08	59	4.43	1.75	65	12.71	4.83	61
SR	6.13	0.93	18	3.42	0.74	28	9.55	1.67	21
FP	5.20	–	–	2.68	–	–	7.88	–	–
Kanpur									
SSNM	9.23	2.34	34	5.69	1.15	25	14.91	3.48	30
SR	8.28	1.39	20	5.26	0.73	16	13.55	2.12	19
FP	6.89	–	–	4.54	–	–	11.43	–	–
Modipuram									
SSNM	10.18	3.16	45	6.10	1.55	34	16.28	4.71	41
SR	7.73	0.70	10	5.41	0.86	19	13.14	1.56	14
FP	7.03	–	–	4.55	–	–	11.58	–	–
Varanasi									
SSNM	7.03	1.00	17	4.19	0.81	24	12.46	1.93	18
SR	6.53	0.50	8	3.85	0.47	14	11.61	1.08	10
FP	6.02	–	–	3.39	–	–	10.53	–	–
Mean over locations									
SSNM	8.20	2.17	36	4.86	1.30	41	12.79	3.30	35
SR	6.95	0.92	15	4.31	0.74	21	11.04	1.55	16
FP	6.03	–	–	3.56	–	–	9.49	–	–
CD at 5%	0.59	–	–	0.25	–	–	0.71	–	–

CD = critical difference

The productivity of rice-wheat system, as a whole was highest under SSNM (12.79 t/ha), which was 35% more than FP (9.49 t/ha). The productivity gain due to SSNM in rice plus wheat through SSNM over FP ranged from 1.69 t/ha at Ludhiana to 5.19 t/ha at Sabour, indicating an almost three-fold difference among locations. The productivity gain under SSNM had a yield improvement of 3 t/ha or more at 6 out of 9 locations. The extent of yield increase was more than 4 t/ha at 4 sites including Sabour, Ranchi, Faizabad, and Modipuram.

Economic analysis

SSNM in rice cultivation involved an additional expenditure ranging from Rs.1,140 to 6,210/ha (average Rs.3,550/ha) over FP (**Table 3**). This additional expenditure generated an average extra produce (grain + straw) worth Rs.19,740/ha within a range of Rs.9,130 to 29,670/ha. After deducting additional costs, the resulting average net return was Rs.16,190/ha with a benefit-to-cost ratio (BCR) of 4.6.

In wheat, moving from FP to SSNM involved an additional fertiliser expenditure of Rs.340 to 3,130/ha (average Rs.1,520/ha). Generally, lower additional investment needed for wheat is due to that cost incurred for S and micronutrients application in rice only. Since wheat has also benefited from the residual effects of these nutrients, the net returns have been affected proportionately. The additional net return under SSNM over FP ranged from Rs.4,060/ha at Ludhiana to Rs.22,400/ha at Sabour (**Table 3**). As expected, the improvements in wheat were associated with higher BCRs compared to rice because of high additional input costs debited to rice for S and micronutrients.

The cumulative effect of SSNM under the entire RWCS involved an additional expenditure of Rs.5,070/ha and an additional produce value worth Rs.36,010/ha (gross) and Rs.30,940/ha (net) after deducting the extra input costs. This was achieved at an average BCR of 6.1 which means that every extra rupee invested in nutrients for SSNM over FP produced an extra crop value of Rs.6.1. Any technological improvements with a BCR of 5 would be highly remunerative and suitable for large-scale adoption.

Table 3. Changes in economic returns while shifting from farmer nutrient management practice to SSNM in the rice- wheat cropping system[1].

		SSNM vs farmer practice			
Location	Crop	Extra cost of fertiliser, Rs./ha	Value of extra produce, Rs./ha	Net return, Rs./ha	Benefit-to-cost, Rs. per Rs. invested in nutrients
Sabour	Rice	2,920	29,670	26,750	9.2
	Wheat	1,780	24,180	22,400	12.6
	System	4,700	53,850	49,150	10.5
Palampur	Rice	3,210	10,340	7,130	2.2
	Wheat	1,520	15,890	14,370	9.4
	System	4,730	26,230	21,500	4.6
Ranchi	Rice	3,300	23,290	19,990	6.1
	Wheat	1,780	18,470	16,690	9.4
	System	5,080	41,760	36,680	7.2
R.S. Pura	Rice	1,990	15,510	13,520	1.5
	Wheat	3,130	16,950	13,820	4.4
	System	5,120	32,460	27,340	2.5
Ludhiana	Rice	3,130	11,790	8,660	2.8
	Wheat	840	4,900	4,060	4.8
	System	3,970	16,690	12,720	3.2
Faizabad	Rice	4,440	27,980	23,540	5.3
	Wheat	1,940	22,020	20,080	10.3
	System	6,380	50,000	43,620	6.8
Kanpur	Rice	3,970	21,260	17,290	4.4
	Wheat	1,730	14,500	12,770	7.4
	System	5,700	35,760	30,060	5.3
Modipuram	Rice	1,140	28,660	27,520	24.1
	Wheat	340	19,530	19,190	56.1
	System	1,480	48,190	46,710	31.6
Varanasi	Rice	3,680	9,130	5,450	1.5
	Wheat	630	10,140	9,510	15.0
	System	4,310	19,270	14,960	3.5
Mean over location					
	Rice	3,550	19,740	16,190	4.6
	Wheat	1,520	16,270	14,750	9.7
	System	5,070	36,010	30,940	6.1

[1]Economic analysis based on 2007/08 costs of nutrients and grain/straw values. Fertiliser (Rs./kg): N, 11; P_2O_5, 17; K_2O, 8; S, 28; zinc sulphate, 21; borax, 36; manganese sulphate, 32; copper sulphate, 14. Grain (Rs./kg): rice, 7.2; wheat, 9.7. Straw (Rs./kg): rice, 1.0; wheat, 1.6.

Agronomic efficiency

Agronomic efficiency (AE) expressed as kg grain/kg nutrient was greater in SSNM plots compared to FP and the SR. The concomitant increase in AE was 5.4 to 40.6 kg rice/kg and 5.5 to 32 kg wheat/kg for P_2O_5, and 7.3 to 27.1 kg rice/kg and 2.5 to 13.2 kg wheat/kg for K_2O. The corresponding increase in AE for the RWCS was 7.4 to 34 kg rice/kg P_2O_5 and 8.2 to 12.8 kg wheat/kg K_2O (**Table 4**). Average AE for S and Zn in the RWCS was 33.8 and 46.4 kg/kg, respectively. AE was higher in the case of rice (25.2 and 30.7 kg rice/kg S and Zn) than that for its residual availability in wheat (13.3 and 18.1 kg/kg S and Zn). The economic viability computed in terms of Rs./Re. invested for individual nutrients indicated that Re.1 invested in P_2O_5, K_2O, S, and zinc sulphate gave additional returns of Rs.8.4, Rs.8.3, Rs.8.5, and Rs.14.4, respectively.

Apparent nutrient recovery

Averaging across the locations, the apparent recoveries of P, K, and S in rice (ie., 29%, 51%, and 41%, respectively) were comparatively higher than in wheat, which were 26%, 44%, and 15%, respectively (**Table 5**). Thus, rice recovered

Table 4. Agronomic efficiency (AE) expressed as kg grain/kg of P_2O_5, K_2O, S, and Zn application through SSNM in the rice-wheat cropping system.

	AE_P		AE_K		AE_S		AE_{Zn}	
Site	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
Sabour	32.0	20.4	12.2	7.5	27.9	15.6	–	–
Palampur	40.6	5.5	12.4	13.3	13.8	16.5	20.8	28.3
Ranchi	30.6	15.8	16.8	5.7	24.6	11.6	14.9	19.1
R.S. Pura	5.4	9.4	10.9	8.9	10.9	12.5	7.0	4.4
Ludhiana	11.4	7.2	7.3	2.5	18.1	2.5	30.1	4.9
Faizabad	28.4	27.0	8.8	9.0	25.4	13.6	59.0	25.6
Kanpur	40.3	27.2	10.8	5.5	36.0	18.8	43.3	21.6
Modipuram	34.4	32.0	27.1	11.7	53.8	20.1	46.7	16.0
Varanasi	27.5	25.5	10.3	8.7	15.9	7.3	24.1	25.2
Mean over location	27.8	18.9	12.9	8.1	25.2	13.2	30.7	18.1

most of the in-crop S application and recoveries were much lower in wheat. For the RWCS, the apparent recoveries of P, K, and S were 27%, 47%, and 56%, respectively. Increased recovery efficiency under SSNM plots reveals that existing N or NP-driven agriculture cannot sustain high yield agriculture. Adequate supply of P, K, and other deficient secondary and micronutrients is essential (Tiwari, 2002; Dobermann et. al., 2004).

Table 5. Apparent recovery efficiency in maximum economic yield plot fertilised according to SSNM under rice-wheat cropping system.

		Apparent recovery efficiency, %		
Location	Nutrient	Rice	Wheat	RWCS
Sabour	P_2O_5	29	27	28
	K_2O	60	51	55
	S	39	12	50
Palampur	P_2O_5	24	21	22
	K_2O	42	40	41
	S	37	11	48
Ranchi	P_2O_5	25	17	21
	K_2O	50	36	43
	S	28	19	47
R.S. Pura	P_2O_5	22	18	20
	K_2O	47	44	46
	S	40	16	57
Ludhiana	P_2O_5	31	29	30
	K_2O	54	47	51
	S	46	14	60
Faizabad	P_2O_5	31	30	31
	K_2O	55	38	47
	S	47	6	53
Kanpur	P_2O_5	38	36	37
	K_2O	47	47	47
	S	37	22	59
Modipuram	P_2O_5	32	28	30
	K_2O	45	35	40
	S	45	16	61
Varanasi	P_2O_5	28	24	26
	K_2O	59	53	56
	S	49	16	65
Mean over location	P_2O_5	29	26	27
	K_2O	51	44	47
	S	41	15	56
CD at 5%		5	5	5

Conclusion

Considering 50% of the increase in productivity on farmers' fields as compared to the increases observed in these on-station experiments, and only 25% area coverage with SSNM, the total annual increase in RWCS production could be 11 M t for rice and 4.75 M t for wheat. Site- and crop-specific balanced fertilisation in addition to maintaining food security will help sustain soil and environment health due to improved nutrient use efficiency. BC-INDIA

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