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

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The most dominant rice-wheat system of India is showing signs of fatigue, mainly due to inadequate and unbalanced fertilization. The current productivity of 2,130 kg/ha of rice and 2,670 kg/ha of wheat can be doubled by growing hybrid rice and locally recommended high-yielding varieties of wheat and by increasing and balancing fertilizer application rates to correct multiple nutrient deficiencies which are being widely observed. The net return to the extra fertilizer used in SSNM of the rice-wheat system averaged US$732/ha across all nine locations, a return of US$6.1 per US$1 invested.

The rice-wheat cropping system (RWCS) is India's most widely adopted system, covering over 10.5 million (M) ha – mostly in the country's north-west zone (Paroda et al., 1994). The productivity of both rice and wheat is low...2,130 and 2,670 kg/ha, respectively. The combination of poor soil fertility and inadequate, unbalanced, and inefficient use of fertilizers contributes much to this problem (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 program was initiated to evaluate the significance of SSNM towards breaking yield stagnation. The research considers the correction of all existing nutrient deficiencies and the nutrient requirements of regionally attainable yield goals.

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

Selected treatments allowed the assessment of responses to all the deficient nutrients so as to develop viable FBMPs for high yield sustainable agriculture. The SSNM nutrient packages for each site included all major, secondary and micronutrients considered deficient (**Table 1**). Both rice and wheat received N, P, and K while S and micronutrients were only applied to rice. At each location, the efficacy of the SSNM treatment was compared against SR and FP. Omission plots for different treatments were maintained to determine the individual responses to specific nutrients.

The fertilizer sources included urea (46% N), diammonium phosphate (18% N and 46% P_2O_5), potassium chloride (60% K_2O), elemental S, zinc sulfate (21% Zn and 10% S), Borax (10.5 % B), manganese sulfate (30.5% Mn, 17.5% S), and copper sulfate (24% Cu, 12% S). Entire quantities of P, K, S, micronutrients, and one-third of total N recommendation were applied at planting and the remaining N was top-dressed in two equal splits. Hybrid rice cv. PHB 71 and the locally recommended HYV of wheat were grown under optimum management conditions at all locations. Apart from differences in nutrient application rates, all other management practices were

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 = sulfur; B = boron; Mn = manganese; Zn = zinc; Cu = copper; RWCS = rice-wheat cropping system; HYV = high yielding variety; SSNM = site-specific nutrient management; FBMP = fertilizer best management practices; SR = state fertilizer recommendation; FP = farmer fertilizer practice; BCR = benefit-to-cost ratio.

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

the same for the SSNM, SR, and FP plots. Economic comparisons for each of the nutrient management options included analysis of gross and net returns, as well as the additional return per unit investment in each individual crop and the entire RWCS. Results reported here are averages of 3 years of study.

The mean grain yield of rice (unhusked) obtained with SSNM was 8.20 t/ha compared to 6.95 t/ha with the SR and 6.03 t/ha with the FP (**Table 2**). SSNM out-yielded FP by an average of 2.17 t/ha or 36%. The extra yield obtained with rice through SSNM (over FP) ranged from 1 t/ha at Varanasi to 3.27 t/ha at Sabour, indicating an almost three-fold difference amongst locations. This yield advantage with rice was on 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, the rice yield advantages were 3 t/ha or more at Sabour, Faizabad, and Modipuram. Although the SR had a significant edge over FP, the overall response was restricted to only 0.92 t/ha, or 15%.

Averaged over the 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 the locations, the SSNM plot out-yielded the FP by 1.30 t/ha, or 41%. The additional yield obtained with SSNM over FP ranged from 0.39 t/ha at Ludhiana to 1.92 t/ha at Sabour indicating an almost 5-fold difference amongst locations. This yield advantage was 30% or more at 6 out of 9 locations. Similarly, the productivity gain over FP by 1.0 t/ha or more was at 7 out of 9 locations. As with rice, significant yield response for SR was also obtained in wheat and the magnitude of yield increase over FP was 0.74 t/ha, or 21%.

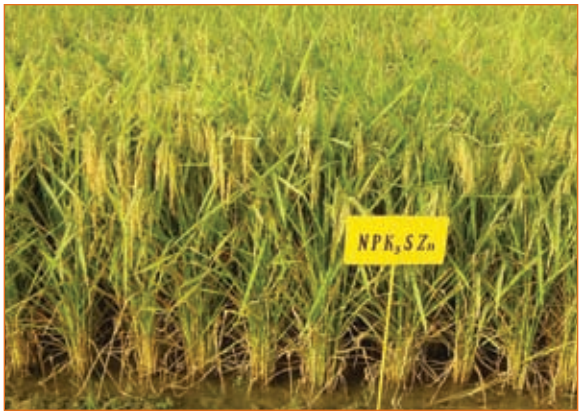
The productivity of the entire rice-wheat system was highest under SSNM (12.79 t/ha), which was 35% more than FP (9.49 t/ha). The productivity gain due to SSNM in rice plus wheat through SSNM over FP ranged from 1.69 t/ha at Ludhiana to 5.19 t/ha at Sabour, indicating an almost 3-fold difference among 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.

SSNM in rice cultivation involved an additional expenditure ranging from US$27 to US$147/ha (average US$84/ha) over the FP (**Table 3**). This additional expenditure generated an average extra produce value (rice grain plus straw) worth US$467/ha within a range of US$216 at Varansi to US$702/ha

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

	Rice			Wheat			Rice-wheat system		
	Yield,	Response		Yield,	Response		Yield,	Response	
Treatment	t/ha	t/ha	%	t/ha	t/ha	%	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 location									
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



Fertilizer treatments in rice plot.

at Sabour. After deducting the additional costs, the resulting average net return was US$383/ha with a BCR (US$ per US$ investment) of 4.6.

In wheat, moving from FP to SSNM involved an additional fertilizer expenditure of US$8 to US$74/ha with an average of US$36/ha (**Table 3**). Generally, the lower additional investment needed for wheat as compared to rice was due to the cost incurred for S and micronutrients application in rice only. Since wheat has also benefited from the residual effect of these nutrients, the net returns have been affected proportionately. The additional net return under SSNM over FP ranged from US$96 at Ludhiana to US$530 at Sabour. As expected, the improvements in wheat were associated with higher BCRs compared to rice because of the high additional input cost debited to rice for S and micronutrients.

The cumulative effect of SSNM under the entire RWCS involved an additional average expenditure of US$120/ha and resulted in an additional produce value worth US$852/ha (gross) and US$732/ha (net) after deducting the extra input costs. This was achieved at an average BCR of 6.1, which means that every extra US$1 invested in nutrients for SSNM over FP produced an extra crop value of US$6.1. Any technological improvements with a BCR of 5 would be highly remunerative and suitable for large-scale adoption. Considering 50% of the increase in productivity on farmer fields as compared to the increases observed in these on-station experiments, and only a 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 fertilization in addition to maintaining food security will help sustain soil and environment health due to improved nutrient use efficiency. BC

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

	Crop	SSNM versus Farmer practice			
Location		Extra cost of fertilizer, US$/ha	Value of extra produce, US$/ha	Net return, US$/ha	Benefit-to-cost, US$ per US$ extra invested in nutrients
Sabour	Rice	69	702	633	9.2
	Wheat	42	572	530	12.6
	System	111	1,274	1,163	10.5
Palampur	Rice	76	246	170	2.2
	Wheat	36	376	340	9.4
	System	112	622	510	4.6
Ranchi	Rice	78	551	474	6.1
	Wheat	42	437	395	9.4
	System	120	988	869	7.2
R.S. Pura	Rice	147	367	220	1.5
	Wheat	74	401	327	4.4
	System	221	768	547	2.5
Ludhiana	Rice	74	279	205	2.8
	Wheat	20	116	96	4.8
	System	94	395	301	3.2
Faizabad	Rice	105	662	557	5.3
	Wheat	46	521	475	10.3
	System	151	1,182	1,032	6.8
Kanpur	Rice	94	503	409	4.4
	Wheat	41	343	302	7.4
	System	135	846	711	5.3
Modipuram	Rice	27	678	651	24.1
	Wheat	8	462	454	56.8
	System	35	1,140	1,105	31.6
Varanasi	Rice	87	216	129	1.5
	Wheat	15	240	225	15.0
	System	102	456	354	3.5
Mean over location					
	Rice	84	467	383	4.6
	Wheat	36	385	349	9.7
	System	120	852	732	6.1

[1]Economic analysis based on 2007/08 costs of nutrients and grain/straw values. Fertilizer (US$/kg): N, 0.26; P_2O_5, 0.41; K_2O, 0.19; S, 0.66; zinc sulfate, 0.50; borax, 0.85; manganese sulfate, 0.75; copper sulfate, 0.33. Grain (US$kg): rice, 0.17; wheat, 0.23. Straw (US$/kg): rice, 0.025; wheat, 0.038.
Note: The government of India subsidizes the cost of fertilizer for farmers and controls the prices for crops.

Acknowledgment

The authors greatly appreciate and acknowledge the support of IPNI and the contribution of the Chief Agronomist of various centers of the All India Coordinated Research Project On Cropping Systems involved in the project. *IPNI Project #NWZ-India-73*

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