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Site-Specific Nutrient Management for Maximum Economic Yield of the Rice-Wheat Cropping System

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The rice-wheat cropping system (RWCS) in India accounts for about one-third of the area of both rice and wheat grown in South Asia and provides staple food grain for more than 400 million people or about 8% of the world's population. This paper discusses a field-specific nutrient management approach that has been adopted as a strategy capable of assuring restoration of soil fertility and sustaining high yields.

Of the 12.5 million hectares (M ha) of estimated area managed under RWCS in South Asia, India alone accounts for 10 M ha. Because RWCS is the most widely practiced annual crop rotation in India, and both component crops are staple food grains, a sustained high productivity of RWCS is necessary for national food security. For over a decade, RWCS yields have either stagnated or declined, particularly in high productivity zones. The most important reason is a decline in factor productivity resulting from depletion of soil fertility and emergence of multiple nutrient deficiencies.

Recent surveys in the Upper-Gangetic Plain zone revealed that farmers apply greater than recommended doses of both nitrogen (N) and phosphorus (P), but ignore the replenishment of other nutrients. Such an unbalanced use of fertilizer not only aggravates the deficiency of potassium (K), sulfur (S) and micronutrients in the soil, but it also proves uneconomic and environmentally unsafe. The high yield potential of modern varieties can never be exploited with inadequate and unbalanced fertilization. Site-specific nutrient management (SSNM), considers indigenous nutrient supply of the soil and productivity targets as a strategy to provide sustained high yields on one hand, and assure restoration of soil fertility on the other.

The positive effect of SSNM on rice productivity was related to higher number of grains/panicle, grain weight/panicle, and other factors.

Materials and Methods

A field experiment at Project Directorate for Cropping System Research experimental station, Modipuram, Meerut, was conducted during 2002-03 on a Typic Ustochrept sandy loam soil located in western Uttar Pradesh. The soil is very deep (more than 2 m), well drained, and Gangetic alluvium. The experiment was comprised of 12 treatments (**Table 1**).

Table 1. Treatment details for on-station experiments.

Treatments	Rice							Wheat		
$SSNM_1$	N_{170}	P_0	K_{120}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_0	K_{120}
$SSNM_2$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{120}
$SSNM_3$	N_{170}	P_{30}	K_{80}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{80}
$SSNM_4$	N_{170}	P_{30}	K_{40}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{40}
$SSNM_5$	N_{170}	P_{30}	K_0	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_0
$SSNM_6$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_7	Mn_{17}	B_0	N_{150}	P_{30}	K_{120}
$SSNM_7$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_7	Mn_0	$B_{0.6}$	N_{150}	P_{30}	K_{120}
$SSNM_8$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_0	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{120}
$SSNM_9$	N_{170}	P_{30}	K_{120}	S_0	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{120}
LAR	N_{150}	P_{75}	K_{75}	–	Zn_5	–	–	N_{150}	P_{60}	K_{60}
STLR	N_{180}	P_{55}	K_{55}	–	Zn_5	–	–	N_{180}	P_{45}	K_{45}
FP	N_{180}	P_{60}	–	–	Zn_5	–	–	N_{180}	P_{60}	–

The SSNM recommendation for a yield target of 10 t rice grain/ha was 170 kg N, 120 kg K_2O, 20 kg S, 17 kg manganese (Mn), 7 kg zinc (Zn), and 0.6 kg boron (B)/ha. These nutrients, in order, were applied as urea, muriate of potash, gypsum, zinc sulfate, manganese sulfate, and sodium tetraborate. As the soil was high in available P, a maintenance dose of 30 kg P_2O_5/ha was applied as diammonium phosphate (DAP) in treatments $SSNM_2$ to $SSNM_9$. Healthy 25-day-old seedlings of hybrid rice cv. PHB 71 were transplanted on July 26 during 2002 and the crop was harvested on November 6, 2002. Wheat (cv. PBW 343) was sown on November 28, 2002, on the same layout with the applications of NPK, only to assess the cumulative applications of NPK and carryover effect of secondary and micronutrients. The crops were grown under irrigation with adoption of a recommended package of cultural practices. The economics of various fertilizer treatments were determined using total cost of crop cultivation, plus cost of different operations performed and inputs.

Yield and Yield Attributes

Rice: Fertilizer application according to the SSNM schedule for treatment $SSNM_2$ resulted in the highest rice grain yield of 9.95 t/ha, whereas farmer practice (FP) produced the lowest yield of 7.29 t/ha (**Table 2**). For the treatments $SSNM_2$ to $SSNM_5$ receiving varying K rates from 0 to 120 kg K_2O/ha, a statistically significant ($p<0.05$) increase in yield was recorded with incremental rates up to 80 kg K_2O/ha. Compared with the zero-K control, the treatment receiving 80 kg K_2O/ha gave 0.97 t/ha additional rice yield. Fertilizer K applied beyond 80 kg K_2O/ha did not produce more yield. Interestingly, the yield differences between zero-K and 40 kg K_2O/ha treatments were non significant, which indicated that on K-deficient soil, a high yielding genotype may not respond to sub-optimal K fertilization rates. This may also explain the non significant response to K applied as per state recommendation in many other studies.

Treatments omitting either S or micronutrients resulted in a marked yield loss, indicating the significance of replenishment of these nutrients for achieving high yield targets. Compared with $SSNM_2$, yield reductions were 0.48 t/ha (-B), 0.95 t/ha (-Mn), 1.24 t/ha (-Zn), and 2.03 t/ha (-S).

Although the treatments receiving fertilizers according to local ad-hoc recommendation (LAR) or state soil-testing laboratory

Table 2. Yield and yield attributes of hybrid rice as influenced by site-specific nutrient management practices.

Treatment	Grain yield, t/ha	Yield attributes: Number of panicles/m^2	Number of grains/panicle	Grain weight/panicle, g	Number of unfilled grains/panicle
$SSNM_1$	9.86	198	180	5.30	29
$SSNM_2$	9.95	215	176	5.34	32
$SSNM_3$	9.72	201	182	5.22	29
$SSNM_4$	9.18	210	167	5.09	31
$SSNM_5$	8.75	210	147	4.66	37
$SSNM_6$	9.47	206	171	4.92	42
$SSNM_7$	9.00	190	165	4.89	42
$SSNM_8$	8.71	193	156	4.76	47
$SSNM_9$	7.92	196	142	4.52	47
LAR	8.03	190	133	4.12	40
STLR	7.94	188	138	4.30	42
FP	7.29	193	128	4.08	49
CD ($p<0.05$)	0.51	11	8	0.17	5

recommendation (STLR) had significantly higher yields than FP, the best SSNM schedule out-yielded LAR or STLR by about 2.0 t/ha. Straw yields (data not shown) also showed similar treatment behaviors, although the differences were not as sharp as in case of grain yield. Balanced fertilization resulted in a greater harvest index.

The positive effect of SSNM on rice productivity was the cumulative increase measured in different yield-contributing characters. Whereas number of panicles/m^2 remained largely unaffected by fertilizer management options, parameters like number of grains/panicle and grain weight/panicle were significantly greater in SSNM treatments compared with those under FP, LAR, or STLR. Balanced fertilization also increased grain filling in the panicles and had fewer unfilled grains/panicle (29 to 32), as recorded in $SSNM_1$ to $SSNM_4$, compared with FP, LAR, or STLR, or SSNM treatments not receiving a secondary or micronutrients.

Wheat: The grain yield of wheat grown on the same experimental treatment layout, but without the application of secondary and micronutrient, was also the highest (5.94 t/ha) with the $SSNM_2$ treatment, and the lowest (4.53 t/ha) using FP (**Table 3**). As in rice, wheat responded to K application up to 80 kg K_2O/ha, and in treatments receiving K beyond 80 kg K_2O/ha there was no yield benefit. Yields of treatments receiving no P ($SSNM_1$) and 30 kg P/ha ($SSNM_2$) were statistically comparable, but yield difference was wider as compared to rice.

Table 3. Yield and yield attributes of wheat (2002-03) as influenced by site-specific nutrient management.

Treatment	Grain yield, t/ha	No. of ears/m	No. of grains/ear	Grain wt/ear
$SSNM_1$	5.71	249	40	1.78
$SSNM_2$	5.94	254	49	1.96
$SSNM_3$	5.78	255	48	1.90
$SSNM_4$	5.34	248	45	1.62
$SSNM_5$	5.06	248	40	1.48
$SSNM_6$	5.36	252	42	1.60
$SSNM_7$	5.28	255	42	1.68
$SSNM_8$	4.98	238	38	1.68
$SSNM_9$	4.59	217	34	1.65
LAR	4.86	205	36	1.56
STLR	4.62	216	38	1.52
FP	4.53	218	39	1.44
CD ($p<0.05$)	0.31	29	4	0.22

The magnitude of residual effect of secondary and micronutrient ranged between 0.46 t/ha to 1.35 t/ha. Omitting S or micronutrients from the SSNM package caused marked yield reductions. Omitting S reduced yield by 1.35 t/ha. Among the micronutrients, omission of Zn had the largest impact followed by B and Mn. Application of fertilizer following LAR

Table 4. Net profit (US$/ha) as influenced by site-specific nutrient management in the rice-wheat system (2002-03), Uttar Pradesh.

Treatment	Total cost of cultivation	Total Net return	Increase over FP	Increase over STLR	Increase over LAR	Increase over K_0	Increase over B_0	Increase over Mn_0	Increase over Zn_0
$SSNM_1$	739	1,126	462	374	367	199	117	131	249
$SSNM_2$	797	1,135	471	384	377	208	126	141	259
$SSNM_3$	782	1,103	439	352	345	176	94	109	227
$SSNM_4$	766	998	334	247	240	71	-11	4	122
$SSNM_5$	750	927	263	176	169	0	-82	-67	51
$SSNM_6$	791	1,009	345	257	250	82	0	15	132
$SSNM_7$	768	994	330	243	236	67	-15	0	118
$SSNM_8$	786	877	212	125	118	-51	-132	-118	0
$SSNM_9$	785	735	70	-17	-24	-193	-274	-260	-142
LAR	810	759	94	7	0	-169	-250	-236	-118
STLR	775	752	87	0	-7	-176	-257	-243	-125
FP	776	664	0	-87	-94	-263	-345	-330	-212
CD *($p<0.05$)*	–	93	–	–	–	–	–	–	–

or STLR out-yielded FP, but $SSNM_2$ produced 1.08 t/ha and 1.32 t/ha more, respectively.

Economics

The total costs of the rice-wheat system under the SSNM options were very narrow and ranged between US$750 to 797/ha. However, a great difference in total net return was recorded under SSNM and FP, with corresponding values of US$1,135 and 664/ha, respectively (**Table 4**). The highest net return was obtained with the $SSNM_2$ treatment. Among the SSNM treatments 2 to 5 the profitability increased with increasing doses of K_2O, but it became non-significant beyond 80 kg/ha K_2O. Omission of K in SSNM application schedule resulted in 22% and 19% decline in net profitability over its 120 or 80 kg K_2O application rate. The decrease in net income resulting from omitting secondary nutrients and micronutrients ranged between US$126 to 400/ha. Omission of S caused the highest loss in profitability, followed by Zn, Mn, and B. Interestingly, omission of K or application of 40 kg K_2O in a SSNM schedule caused a negative impact on profitability, even with balanced application of secondary and micronutrients, indicating that their full potential is not possible without adequate K. **The economic profitability of the LAR and STLR were similar, but significantly better than FP. Net returns with LAR/STLR were about US$375/ha under $SSNM_2$.** BC

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