Nutrient Depletion in the Rice-Wheat Cropping System of the Indo-Gangetic Plains

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Despite being a major source of food security and livelihood for over a billion people, the rice-wheat cropping system of the most fertile Indo-Gangetic Plains region of India is under stress due to depletion of native nutrient reserves, emergence of multi-nutrient deficiencies, and consequent decline in factor productivity of applied nutrients. The authors discuss the status of plant nutrient use, nutrient removal, and nutrient balances for this system with the aim to enhance productivity and develop balanced and efficient fertilizer management strategies for the region.

The rice-wheat cropping system (RWCS) is the world's largest agricultural production system occupying 24 million hectares (M ha) throughout India and China alone. In the Indo-Gangetic plains region of India, the cropping system spreads over a vast area spanning from Punjab in the Northwest to West Bengal in the East. More than 85% of the system is located on the plains of the Indus and Ganges, and is conveniently divided into four sub-regions: the Trans-Indo-Gangetic Plains (TGP), Upper Indo-Gangetic Plains (UGP), Middle Indo-Gangetic Plains (MGP), and Lower Indo-Gangetic Plains (LGP), as shown in **Figure 1**.

For over a decade, RWCS yields in high productivity zones have either stagnated or declined. The most important reason is a decline in factor productivity resulting from depletion of soil fertility. The system commonly shows signs of fatigue and is no longer exhibiting increased production with higher input use based on the current pattern. Even with current generalized recommended rates of fertilization for this system, a negative balance of the primary nutrients exists. Recent surveys in the Upper-Gangetic Plain zone reveal that farmers apply greater than recommended rates 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 under this scenario.

Materials and Methods

A primary survey collected regional data on area, production, productivity, and nutrient input use in the Indo-Gangetic Plain region covering Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal, involving 40 districts, 360 villages, and 3,309 farmers (Sharma et al., 2003). Nutrients (NPK) added to the soil through chemical fertilizers, organic manures, crop residues, and irrigation water were estimated using aver-

age nutrient contents of collected materials. Nutrient removals were determined using estimated production and average nutrient contents of harvested product. Apparent (gross) nutrient balances were calculated by the difference between total crop removal and total nutrient input. A net nutrient balance was calculated based on 50%, 35%, and 70% use efficiencies for N, P, and K used in the system.

Nutrient Addition—Total addition of N, P, and K for the Indo-Gangetic Plains region is 2.96, 0.48, and 0.84 M t, respectively (**Table 1**). Of the total N added, 38% is applied in the TGP followed in order by the UGP (32%), MGP (28%), and the LGP (2%). The corresponding figures for P are: 36%, 37%, 26%, and 1%; and for K: 3%, 52%, 40%, and 5%.

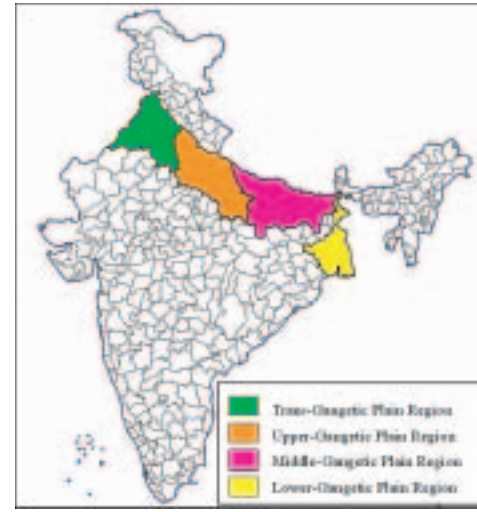


Figure 1. Map of India showing the regions discussed.

Chemical fertilizers are the major N supplying source and provide 81% of the total annual N input (**Figure 2**). Farmyard manures (FYM) and irrigation waters are the next important N sources, each contributing 8 to 9% of the total. Similar to N, 82% of the annual P supply comes from fertilizers. Manure is the second most significant P source and contributes 14% of the total P input. Irrigation water and crop residues contribute relatively small quantities of P. Fertilizer K provides only 12% of the total contribution towards K input to soil. Irrigation water, residue, and manures are the major contributors at nearly 30% each.

Nutrient Removal—Total N removal for the region is estimated at 1.6 M t. TGP alone accounted for 43% of this total, followed by UGP (34%), MGP (21%), and LGP (2.0%). Total P removal for the region is estimated at 433,800 t. Removal for the different sub-regions generally follows the pattern observed for N. However, the order changes on the basis of P removal per hectare, with TGP still having the highest depletion rate of 54.4 kg P/ha, and MGP the lowest (32.1 kg P/ha). Rice-wheat cropping removes an estimated 2.31 M t of K—the highest amongst the three major nutrients. Similar to N removal, TGP accounts for 42% of this total followed by UGP (34%), MGP (21%), and LGP (2%). On a per hectare basis, the MGP region has the lowest rate of removal of 173.3 kg K/ha.

Removal of secondary and micronutrients from the RWCS is also

Table 1. Total NPK addition ('000 t) through FYM, fertilizer, water, and crop residue in RWCS, Indo-Gangetic plains region.

Region	Fertilizer			FYM			Water			Residue			Total		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
TGP	986	172	0	10.9	4.4	13.1	88.9	3.9	98.8	19.8	4.2	73.8	1,127	185	221
UGP	702	119	22.7	153	28.6	85.8	69.9	2.8	72.4	23.4	4.9	87.1	970	156	309
MGP	638	92.8	51.6	89.7	33.3	99.9	52.8	1.8	44.1	10.8	2.4	41.9	807	131	282
LGP	47.8	1.1	13.3	5.3	2.1	6.3	6.9	0.2	5.4	1.0	0.2	4.0	61.2	3.6	32.7
Total	2,374	384	87.6	259	68.4	205	219	8.7	221	55.0	11.6	207	2,965	476	844

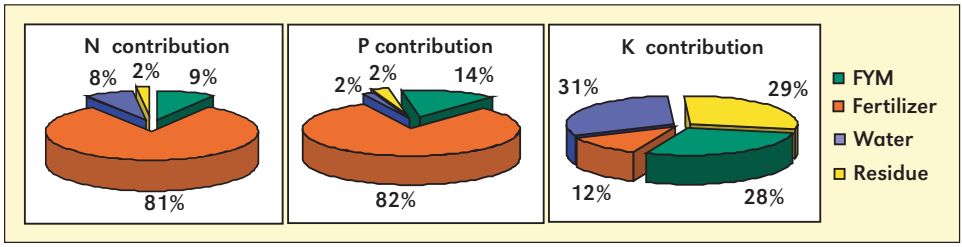


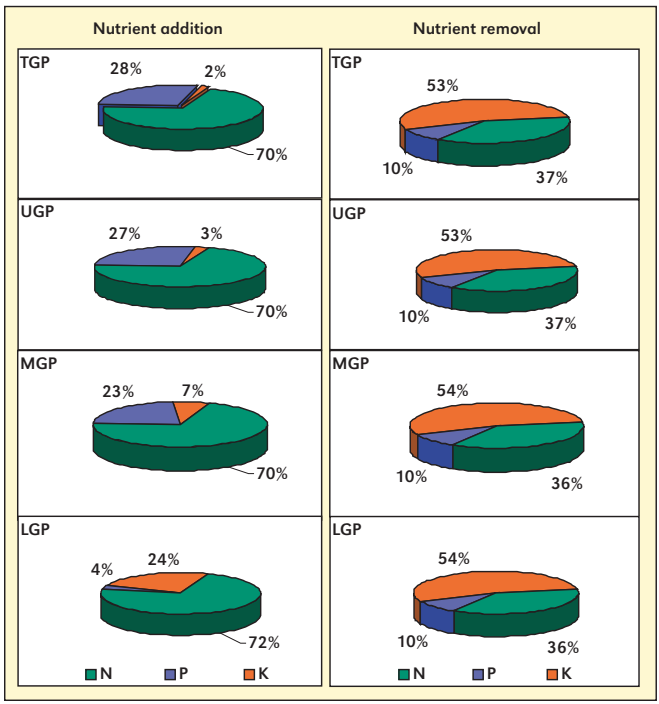
Figure 2. Share of different sources to nutrient contribution (NPK addition) in RWCS, Indo-Gangetic plains region.

alarming (**Table 2**). An average system producing 3.92 t/ha of rice and 3.95 t/ha of wheat annually removes 331,000, 2,900, 3,800, 6,700, 9,200, and 800 t of S, zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and boron (B), respectively. With the exception of Zn, which has a positive balance, additions for these nutrients are almost completely ignored. Many long-term experiments provide evidence of declining productivity and increasing soil micronutrient deficiency can be considered a likely cause.

Table 2 Region-wise nutrient removal ('000 t) in RWCS, Indo-Gangetic plain region.

Sub-regions	Removal of Nutrient								
	N	P	K	S	Zn	Fe	Mn	Cu	B
TGP	682	186	982	142	1.23	1.65	2.87	3.92	0.32
UGP	548	146	782	113	1.00	1.31	2.31	3.16	0.26
MGP	335	92.6	500	69.8	0.60	0.80	1.40	1.92	0.16
LGP	33.5	9.2	49.8	7.0	0.06	0.08	0.14	0.19	0.02
Total	1,598	434	2,314	331	2.89	3.84	6.72	9.19	0.76

Figure 3. Share of NPK addition and removal by RWCS, Indo-Gangetic plains region.



It is clear that N is the dominant nutrient used in all sub-regions…on average, 71% of total NPK added (**Figure 3**). The share of P addition ranges from 4% in the LGP to 28% in the TGP; however, the share of K application is as low as 2% in the TGP, 30% in the UGP, 7% in the MGP, and 24% in the LGP. In contrast, K removal is higher than N removal (54% versus 36%). Phosphorus has the lowest share (10%) of total NPK removal.

Nutrient Balance—The apparent (gross) and net NPK balances for the different sub-regions are provided in **Table 3**. All sub-regions have positive gross N balances which sum to 1.31 M t for the whole. Though the overall gross P balance is also positive, TGP and LGP have negative balances. The gross K balance is negative in all sub-regions and sum to an overall imbalance of -1.59 M t **(Figure 4).**

Table 3 Nutrient balance (Gross and Net, '000 t) in RWCS, Indo-Gangetic plains region.

Sub-regions	Gross nutrient balance			Net nutrient balance		
	N	P	K	N	P	K
TGP	424	-2.1	-797	-129	-122	-852
UGP	401	9.2	-514	-73.4	-91.6	-594
MGP	457	37.7	-262	60.9	-47.0	-333
LGP	27.5	-5.6	-20.9	-3.0	-7.9	-29.5
Total	1,309	39.2	-1,593	-145	-268	-1,810

Note: Net return is based on recovery efficiency of NPK @ 50, 35, and 70%, respectively, in cropping system.

Based on use efficiencies of 50%, 35%, and 70% for N, P and K, the net balances are negative for all three nutrients in all sub-regions, except for N in the MGP. Thus, taking the whole region, annual NPK depletion from soil reserves is estimated at 2.22 M t.

Potassium's share of this deficit is 82% while P and N are 12.5% and 5.5%, respectively. Potassium additions for the different sub-regions range be tween 57.6 to 104.3 kg K/ha...much lower than the range of K uptake by crops (175 to 287 kg K/ha) leading to an average negative balance of 142 kg K/ha. These highly negative K balances are confirmed by a series of long-term experiments conducted with alluvial soils in Ludhiana, Pantnagar, Kanpur, Varanasi, Faizabad, Sabour, and Kalyani under the aegis of the All India Coordinated Project on Cropping Systems Research (Ladha et al. 2003).

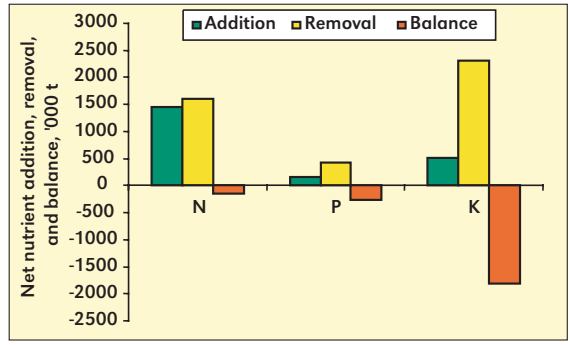


Figure 4. NPK addition, removal, and balance in RWCS, Indo-Gangetic Plains region.

The nutrient balances for the different sub-regions appear to be of serious concern, particularly with respect to soil K. The affect of these negative K balances is also visible on available soil K contents at present, despite high K-supplying capacity of illite-dominated soils and moderate to high non-exchangeable K contents. As the contribution of this pool to crop uptake is greater than the exchangeable pool, available soil K content is not providing a good reflection of the degree soil depletion resulting from actual removal of K by the RWCS. The negative balances for N and P are also troubling.

When considering nutrient use needs, the present and projected crop production goals and nutrient supplying capacity of soils also needs deliberation. For the Indo-Gangetic plains of India, nutrient depletion (particularly of K and P) on a continued basis would lead to serious loss of soil fertility and eventually jeopardize future sustainability. BC

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