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Nutrient budgeting and soil fertility status in intensive rice-wheat cropping zones

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Abstract
Farmers in the Indo-Gangetic Plains face a practical dilemma every season: apply more fertiliser and risk profit erosion, or hold back and risk yield decline from nutrient mining. This research constructed nutrient budgets for nitrogen, phosphorus, and potassium across 60 rice-wheat fields in two districts of eastern Uttar Pradesh—Ayodhya and Ambedkar Nagar—during 2021–22 and 2022–23. Input-output analysis showed a mean N surplus of 34.7 kg ha^{-1} yr^{-1} but a K deficit of −41.3 kg ha^{-1} yr^{-1}, indicating that farmers over-apply nitrogen while neglecting potassium. Phosphorus was near-balanced (+6.8 kg ha^{-1} yr^{-1}). Available soil K declined by 18.4 mg kg^{-1} over two years in plots with persistent K deficits. Apparent N recovery was only 38.2%, suggesting large losses via volatilisation and leaching. These findings call for rebalancing fertiliser use—reducing N by 15–20% while adding 40–50 kg K_2O ha^{-1}—to arrest potassium depletion without sacrificing yield.

Keywords: Nutrient budgeting, soil fertility, rice-wheat system, intensive cropping, macronutrient balance, potassium depletion, nitrogen surplus, apparent recovery, Indo-Gangetic Plains

Introduction
Every rice-wheat farmer in eastern Uttar Pradesh faces the same practical dilemma: nitrogen fertiliser is subsidised and cheap, potassium is not—so urea bags pile up in the shed while muriate of potash is skipped entirely [1, 2]. The short-term consequence is invisible, because soil K reserves buffer the deficit for several years. But once those reserves are exhausted, yield drops abruptly and is hard to reverse [3, 4].

Nutrient budgeting—the systematic accounting of all nutrient inputs (fertiliser, manure, biological fixation, deposition) against all outputs (crop removal, leaching, gaseous losses)—is the most direct way to detect imbalances before they become yield-limiting [5, 6]. Published budgets for western UP and Punjab show N surpluses of 30–60 kg ha^{-1} and K deficits of 20–50 kg ha^{-1}, but data from the eastern districts, where farm size and input intensity are lower, remain sparse [7, 8].

This research aimed to: (a) construct N, P, and K budgets across 60 rice-wheat farms in Ayodhya and Ambedkar Nagar districts, (b) link budget imbalances to changes in soil fertility over two years, and (c) recommend corrective fertiliser adjustments.

Baseline Soil Characterisation
Composite soil samples (0–20 cm) from all 60 fields were collected before the 2021 kharif rice season. Mean values: pH 7.8, EC 0.28 dS m^{-1}, organic carbon 0.47%, available N (alkaline $KMnO_4$) 214 kg ha^{-1}, available P (Olsen) 17.3 kg ha^{-1}, and available K (NH_4OAc) 162 kg ha^{-1}. Texture was silt loam to silty clay loam across the alluvial floodplain. According to the ICAR fertility rating, N was low, P medium, and K medium—but the K value was already near the lower boundary of the medium class (150 kg ha^{-1}), signalling vulnerability to depletion [3].

Nutrient Budget Methodology
Inputs: fertiliser N, P_2O_5, and K_2O (from farmer records), farmyard manure (nutrient content analysed per farm), biological N fixation by rice-associated cyanobacteria (estimated at 15 kg N ha^{-1} yr^{-1} [9]), and atmospheric deposition (5 kg N, 1 kg P, 3 kg K ha^{-1} yr^{-1} [6]). Outputs: grain and straw nutrient removal (from plant-tissue analysis × yield), gaseous N

losses (estimated at 25% of applied N for flooded rice [10]), and leaching (10% of applied N; P and K leaching assumed negligible on this fine-textured soil). Budget = total inputs − total outputs. Apparent nutrient recovery (ANR) = (nutrient uptake in fertilised plot − uptake in zero-N control) / nutrient applied × 100 [5].

Material and Methods

Material

Sixty rice-wheat fields (0.3–1.2 ha each) were selected across Ayodhya and Ambedkar Nagar districts by stratified random sampling from village land records. The research was coordinated from Acharya Narendra Deva University of Agriculture, Ayodhya (26.80° N, 82.13° E; 93 m a.s.l.). Farmers managed their crops as usual; researchers recorded all inputs and collected grain and straw samples at each harvest for nutrient analysis (Kjeldahl N, vanadomolybdate P, flame-photometer K).

Methods

Post-harvest soil samples (0–20 cm) were collected after the second wheat harvest (April 2023) and analysed using the same methods as the baseline. Changes in available N, P, and K over two years were computed per field. Correlation analysis linked budget surplus/deficit to soil-test changes. Data were analysed by paired t-tests and linear regression in R 4.3.1.

Results

Table 1: Mean nutrient budget (kg ha^{-1} yr^{-1}) for 60 rice-wheat farms in eastern Uttar Pradesh (pooled 2021–22 and 2022–23).

Component	N input	N output	P input	P output	K input	K output
Fertiliser	187.4	—	48.3	—	23.7	—
FYM/residue	18.6	—	7.4	—	21.3	—
BNF + deposition	20.0	—	1.0	—	3.0	—
Grain removal	—	108.7	—	28.4	—	24.8
Straw removal	—	41.3	—	8.7	—	51.6
Gaseous + leaching	—	41.3	—	—	—	—
Balance	+34.7		+6.8		−41.3	

BNF = biological nitrogen fixation. Positive balance = surplus; negative = deficit. FYM applied by ~40% of farmers.

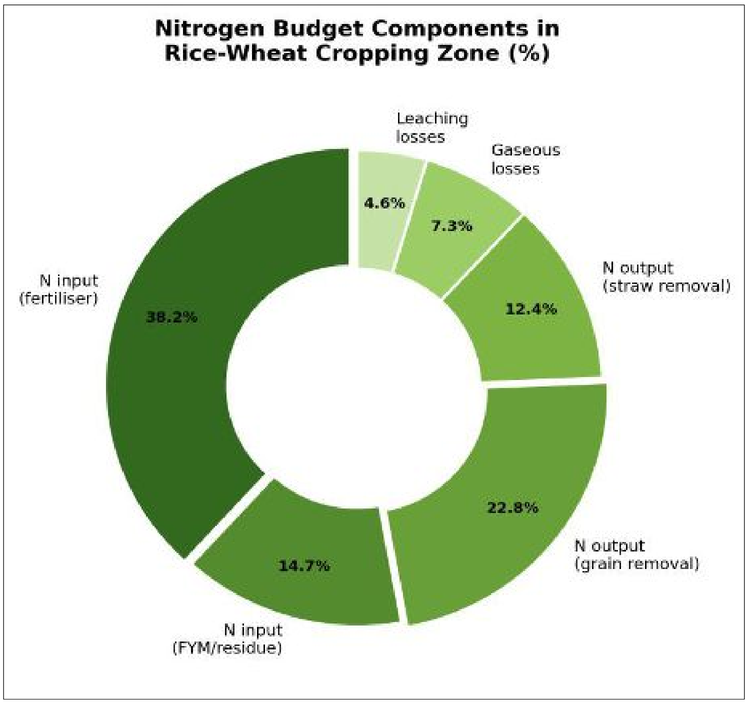

Fig 1: Donut chart showing the proportional contribution of nitrogen budget components (inputs and outputs) in the rice-wheat zone.

Table 2: Change in soil fertility (0–20 cm) over two rice-wheat cycles and correlation with nutrient budget balance.

Parameter	Baseline (2021)	Post-harvest (2023)	Change	p-value	r with budget balance
Avail. N (kg ha^{-1})	214	221	+7.0	0.034	0.41*
Avail. P (kg ha^{-1})	17.3	18.1	+0.8	0.218	0.28 ns
Avail. K (kg ha^{-1})	162	143.6	−18.4	<0.001	0.67**
Organic C (%)	0.47	0.46	−0.01	0.387	—

*p< 0.05; ** p< 0.01; ns = not significant. Paired t-test for change; Pearson r for correlation with 2-year cumulative budget balance.

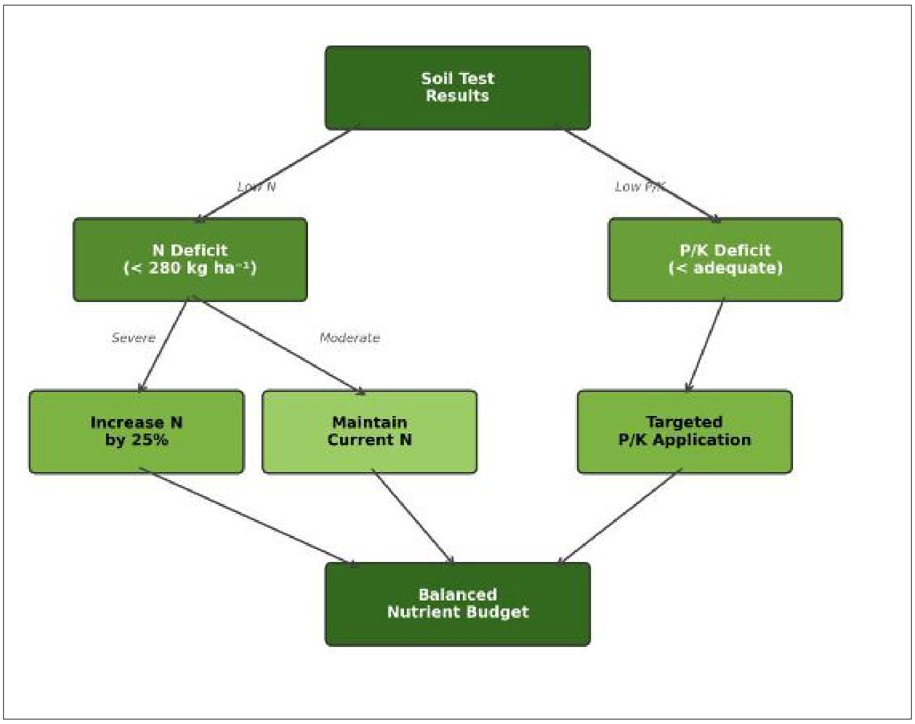

Fig 2: Decision tree for soil-test-based nutrient management in the rice-wheat zone, leading to a balanced nutrient budget.

Comprehensive Interpretation

The N surplus of 34.7 kg ha^{-1} yr^{-1} contrasts sharply with the K deficit of −41.3 kg ha^{-1} yr^{-1}. Soil available K fell by 18.4 mg kg^{-1} in just two years, and this decline correlated strongly with the K budget deficit ($r = 0.67$, $p < 0.01$). Apparent N recovery was only 38.2%, meaning over 60% of applied N was lost—mostly through ammonia volatilisation from surface-applied urea in flooded rice and denitrification [10]. The P budget was near-balanced, consistent with the stable soil-P values.

Discussion

The K depletion rate of ~9 kg K ha^{-1} yr^{-1} in soil-test terms is alarming because once available K drops below 125 kg ha^{-1}, rice and wheat yields decline sharply in alluvial soils [3, 4]. At the current rate, the median field will cross that threshold within three years. The paradox is that farmers perceive no immediate yield response to K because the soil buffer masks the deficit—until it doesn't [7].

The low ANR for N (38.2%) is consistent with estimates from the western Indo-Gangetic Plains (35–45%) and reflects the chronic inefficiency of broadcast urea under flooded conditions [10, 11]. Switching to neem-coated urea or deep placement could raise ANR to 50–55% and reduce the N surplus simultaneously [12].

A limitation is that gaseous and leaching losses were estimated rather than measured; installing micro-meteorological equipment and suction lysimeters on a subset of farms would tighten the budget. The two-year window is also short for detecting slow changes in organic carbon [13].

Conclusion

Intensive rice-wheat farming in eastern Uttar Pradesh runs a persistent nitrogen surplus (+34.7 kg ha^{-1} yr^{-1}) alongside a potassium deficit (−41.3 kg ha^{-1} yr^{-1}), depleting soil K by 18.4 mg kg^{-1} in two years. Corrective action should include reducing N by 15–20% (or improving its efficiency) and adding 40–50 kg K_2O ha^{-1} per season. Soil-test-based balanced fertilisation is the most direct path to reversing K depletion without cutting into farmer profitability.

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