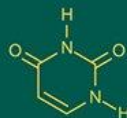


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Assessment of soil quality and crop productivity for reducing yield gaps in farmers' fields

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Abstract

A field study was conducted in farmers' fields at six locations, namely Chinsurah, Titabar, Pantnagar, Kanpur, Kaul and Karaikal, to assess variability in soil nutrient-supplying capacity and its relationship with rice productivity under farmers' fertilizer practices and recommended nutrient management. The study also aimed to develop and validate site-specific fertilizer prescriptions for achieving targeted rice yields. Considerable variation in grain yield was observed between low-and high-yielding farmers' fields across the locations. Mean grain yield ranged from 2.38 to 4.73 t ha⁻¹ at Chinsurah, 2.48 to 3.43 t ha⁻¹ at Titabar, 4.76 to 6.59 t ha⁻¹ at Kanpur, 4.83 to 5.84 t ha⁻¹ at Pantnagar, 3.83 to 4.36 t ha⁻¹ at Karaikal and 1.44 to 8.80 t ha⁻¹ at Kaul. Location-specific fertilizer prescriptions were developed based on soil nutrient status and targeted yield requirements. The soil quality index was highest at Pantnagar, while the remaining locations showed comparatively similar soil quality status. The study indicated substantial field-to-field variability in soil fertility and rice productivity, highlighting the importance of site-specific nutrient management for reducing yield gaps in farmers' fields.

Keywords: Rice, soil quality index, soil fertility, yield gap, nutrient management, targeted yield, fertilizer recommendation

Introduction

Sustainable rice production is essential for meeting the growing demand for food under increasing competition for land, water and other agricultural resources. In India, substantial variation in rice productivity among farmers' fields remains a major constraint to sustainable production. Yield-gap analysis provides a useful approach for quantifying the difference between attainable yields and the yields actually achieved under farmers' management conditions.

Balanced and efficient nutrient management is critical for exploiting the yield potential of modern rice genotypes. However, fertilizer practices in many regions continue to rely on generalized recommendations that do not adequately account for spatial variability in soil nutrient-supplying capacity, crop nutrient requirements and prevailing management practices. Such blanket recommendations may result in either insufficient or excessive nutrient application, leading to nutrient imbalance, inefficient fertilizer use and reduced sustainability.

The introduction of high-yielding rice cultivars with greater yield potential further emphasizes the need for location-specific nutrient management. Therefore, assessment of soil fertility, soil quality and crop productivity at the farmers' field level is important for identifying yield constraints and developing appropriate fertilizer strategies. In this context, the present study was undertaken to evaluate soil quality and productivity variability across farmers' fields and to develop site-specific nutrient recommendations aimed at reducing yield gaps and improving the sustainability of rice production.

Materials and Methods

The investigation was carried out during *kharif* 2019 in farmers' fields located around six selected centres: Chinsurah (46 farmers), Titabar (30 farmers), Pantnagar (50 farmers), Kanpur (20 farmers), Kaul (24 farmers) and Karaikal (22 farmers).

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The study was undertaken to characterize field-level variation in soil nutrient-supplying capacity and examine its association with rice productivity under farmers' existing fertilizer practices and prevailing recommended practices. Another objective was to refine nutrient requirements for achieving specific yield targets and assess the performance of targeted fertilizer recommendations under farmers' field conditions.

A rapid roving survey was conducted in villages surrounding each centre. Information was collected from farmers on rice variety, sowing time, manure and fertilizer use, crop-management practices, yield, weather conditions and general soil characteristics. Based on recorded grain

yields, farmers' fields were classified into low-and high-productivity groups. Soil and plant samples were collected after harvest and analyzed for relevant nutrient parameters. The collected information and analytical results were evaluated to identify the major factors associated with yield differences between low-and high-yielding fields.

Based on the identified nutrient constraints and soil fertility status, site-specific fertilizer recommendations were formulated for the subsequent rice season. These recommendations were implemented in selected low-yielding farmers' fields to evaluate their effectiveness in improving rice productivity and maintaining soil health.

Rice productivity in relation to internal supply capacity of nutrients in farmers' fields, *kharif* 2022, Soil, crop and weather data

Parameter	Chinsurah	Kanpur	Kaul	Pantnagar
Variety	Swarna, Khitish, Shatabdi	Pioneer 3727 Kaveri 9090 Arize 6449 Arize 6450 JK Sudha Arize 6444 Pioneer 273037 Pioneer 203031 Pioneer 203067	CSR 30 PB 1847 Vnr 2222 PR 114 PB 1718 PB 1509 PB 1121	Pusa 150 PD 10 PD18 PD 12 Hybrid Local HR47 Sarbat
Crop growth	Good	Good	Good	good
RFD (kg NPK/ha)	Varying-48-24-24, 50-25-25, 60-30-30, 70-35-35, 80-40-40	Varying 120,60,60 150,60,60 120,60,40 150,60,40 120,60,60 120,60,40	-	190:60:40 150:60:40 150:50:30 150:60:50 200:60:40 200:70:45
% Clay	-	-	-	
% Silt	-	-	-	
% Sand	-	-	-	
Soil Texture	-	-	-	
pH	6.49-7.20	7.98-8.82	7.84-8.98	7.0-8.0
EC(mmhos/cm)	0.18-0.44	0.85-1.41	0.19-0.66	0.17-0.54
Org. carbon (%)	0.85-1.28	0.43-0.78	0.44-0.67	0.28-0.72
Avail. N (kg/ha)	378-507	220-289	145-194	118-215
Avail. P ₂ O ₅ (kg/ha)	85-103	14-25	26-44	6.9-17.3
Avail. K ₂ O (kg/ha)	265-320	185-274	323-398	138-219

Results and Discussion

The study was conducted during *kharif* 2022 at Chinsurah, Titabar, Kanpur, Pantnagar and Kaul, while observations at Karaikal were recorded during both *kharif* 2022 and *rabi* 2022. The investigation covered irrigated and shallow lowland rice ecosystems and included a wide range of locally cultivated rice varieties. Farmers' fields were categorized into low-and high-yielding groups based on grain yield. Soil and plant samples collected after harvest were analyzed to assess soil fertility, nutrient uptake and soil quality, and the resulting information was used to develop site-specific nutrient recommendations.

Variation in Soil, Crop and Weather Parameters

Considerable variation was observed in soil properties among farmers' fields across the study locations. The fields differed with respect to soil reaction (pH), organic carbon, texture and available nutrient status. Such spatial variability in soil fertility indicates differences in the inherent nutrient-supplying capacity of individual fields and emphasizes the need for location-specific nutrient management.

The variation in soil characteristics was also reflected in crop performance. Differences in crop yield and nutrient uptake were observed between low-and high-yielding farmers' fields at all locations. These differences suggest that variation in soil nutrient supply, fertilizer management and crop nutrient demand contributed to the observed productivity differences.

Rice Yield and Nutrient Uptake

A wide range of grain yields was recorded across the farmers' fields. At Chinsurah, mean grain yield ranged from 2.38 t ha⁻¹ in low-yielding fields to 4.73 t ha⁻¹ in high-yielding fields. At Titabar, yield increased from 3.10 to 4.75 t ha⁻¹, while at Kanpur it ranged from 4.76 to 6.59 t ha⁻¹. At Pantnagar, mean yield varied from 4.83 to 5.84 t ha⁻¹. Karaikal recorded a relatively narrow range of 3.83-4.36 t ha⁻¹, whereas Kaul showed the largest variation, with yields ranging from 1.44 to 8.80 t ha⁻¹.

The substantial differences between low-and high-yielding fields were accompanied by marked variation in nutrient uptake. The uptake of major nutrients differed considerably

among locations and between yield groups, indicating differences in crop nutrient demand and nutrient-use efficiency. In several locations, soil-test values did not consistently correspond with grain yield and nutrient uptake, particularly under flooded rice conditions. This suggests that conventional soil-test values alone may not fully explain nutrient availability and crop response in submerged soils. However, at some locations, the soil quality index showed a closer association with observed yield and nutrient uptake. These results are in conformity with earlier reported by Bharamappanavara *et al.* (2020) ^[1], Kale *et al.* (2021) ^[4, 5], Gorlapalli *et al.* (2022) ^[3] and Sahoo *et al.* (2022) ^[14].

Soil Quality Index

The soil quality index differed among the study locations and farmer categories, reflecting differences in overall soil health and nutrient-supplying capacity. The lowest soil quality index was observed at Titabar, where considerable variability occurred among fields and soil-test values. In contrast, relatively higher soil quality indices were recorded at Kaul and Pantnagar. The differences in soil quality among locations indicate that assessment of multiple soil attributes can provide a better understanding of field-level productivity constraints than individual soil-test parameters alone. These results are in conformity with earlier reported by Srilatha *et al.* (2019) ^[15], Kale *et al.* (2021) ^[4, 5], Rathod *et al.* (2021) ^[10], Parmar *et al.* (2022) ^[9] and Patel *et al.* (2025) ^[7, 8].

Nutrient Requirement and Site-Specific Fertilizer Recommendations

The nutrient requirement per tonne of grain production varied considerably among the study locations. These estimates were used to determine nutrient demand in relation to grain production and to develop fertilizer prescriptions for specific yield targets. Based on the maximum yield recorded under recommended fertilizer management, target yields were set at 5.0 t ha⁻¹ for Chinsurah, 5.0 t ha⁻¹ for Titabar, 6.5 t ha⁻¹ for Pantnagar,

10.0 t ha⁻¹ for Kaul, 6.5 t ha⁻¹ for Kanpur and 5.0 t ha⁻¹ for Karaikal. The location-specific fertilizer prescriptions demonstrated the need to move beyond blanket fertilizer recommendations. Differences in soil nutrient supply, crop nutrient uptake and nutrient requirement per unit of grain production resulted in varying fertilizer requirements among locations. The relatively high estimated requirements of phosphorus and potassium may be associated with low recovery of applied phosphorus and greater potassium accumulation by rice. These findings indicate considerable scope for improving nutrient-use efficiency through site-specific nutrient management. These results are in conformity with earlier reported by Sharma *et al.* (2022) ^[11], Patel *et al.* (2025) ^[7, 8] and Kumar *et al.* (2025) ^[6], Brajendra *et al.* (2025) ^[12] and Zoureen *et al.* (2025) ^[17].

Yield Gap Analysis

A substantial yield gap was observed between low-and high-yielding farmers' fields at all study locations. The highest yield gap was recorded at Kaul (83.6%), followed by Chinsurah (49.6%), Kanpur (27.8%), Titabar (27.7%), Pantnagar (17.3%) and Karaikal (17.3%). The magnitude of these differences indicates considerable potential for increasing rice productivity through improved nutrient management and adoption of suitable production practices. The wide yield differences were associated with variations in nutrient uptake, soil quality and fertilizer management. In both recommended and farmers' fertilizer practices, substantial variation in grain yield was observed, indicating that fertilizer doses were not always adequately matched with field-specific nutrient-supplying capacity and crop requirements. Therefore, integrating soil quality assessment, nutrient uptake and yield-gap analysis can provide a more effective basis for refining fertilizer recommendations and improving rice productivity in farmers' fields. These results are in conformity with earlier reported by Sharma *et al.* (2020) ^[12], Sharma *et al.* (2022) ^[11], Patel *et al.* (2025) ^[7, 8] and Kumar *et al.* (2025) ^[6].

Table 1: Rice Productivity in Relation to Soil Nutrient-Supplying Capacity in Farmers' Fields During Kharif 2022: Nutrient Supply Potential and Crop Nutrient Uptake Across Farmer Categories

Categories/Nutrient	Chinsurah (total of 46 sites, 12 low yielders and 21 high yielder sites)			Titabar(total of 30 sites, 21 low yielders and 9 high yielder sites)		
	Minimum	Maximum	Mean*	Minimum	Maximum	Mean**
Grain yield (t/ha)						
Low Yielders	1.76	3.06	2.38	2.00	2.85	2.48
High Yielders	4.27	4.99	4.73	3.10	4.75	3.43
Nutrient uptake (kg/ha)						
Low Yielders						
N	-	-	-	-	-	-
P	-	-	-	-	-	-
K	-	-	-	-	-	-
High Yielders						
N	-	-	-	-	-	-
P	-	-	-	-	-	-
K	-	-	-	-	-	-
Soil Quality Index						
Low yielders(0.7) High Yielders 0.9 (Very High)				Low Yielders 0.3(very poor), High Yielders (0.4)Average		
Categories/Nutrient	Kanpur (Out of 20,5 low yielders, 15 high yielders)			Pantnagar(Out of 60,9 low yielders,51 high yielders)		
	Minimum	Maximum	Mean*	Minimum	Maximum	Mean**
Grain yield (t/ha)						
Low Yielders	4.59	4.98	4.76	4.0	4.5	4.83
High Yielders	5.31	7.18	6.59	5.1	7.4	5.84
Nutrient uptake (kg/ha)						

	Low Yielders					
N	74.88	80.38	77.57	31.2	48.02	40.17
P	26.82	29.42	28.13	2.7	7.0	4.73
K	8.92	9.72	9.30	21.6	40.0	29.81
	High Yielders					
N	83.11	131.45	113.93	28.08	72.52	47.8
P	32.21	54.43	44.59	4.56	13.32	8.58
K	11.24	19.02	14.93	18.2	44.4	28.69
Soil Quality Index						
Low yielders (0.7) High Yielders 0.67(good)				Low yielders (0.6-good) High Yielders (0.8) very good		
Categories/Nutrient	Kaul(Out of 24,14low yielders, 410high yielders)			Karaikal		
	Minimum	Maximum	Mean*	Minimum	Maximum	Mean**
Grain yield (t/ha)						
Low Yielders	1.3	1.7	1.44	3.56	3.92	3.83
High Yielders	7.5	9.9	8.8	4.03	4.65	4.36
Nutrient uptake (kg/ha)						
	Low Yielders					
N	24.3	38.4	30.4	23.96	30.77	26.83
P	8.3	16.1	11.3	9.16	21.49	15.12
K	27.8	44.8	35.4	17.20	49.23	30.12
	High Yielders					
N	96	128	114.5	22.57	54.68	33.83
P	37.87	53.1	42.09	3.84	26.65	16.68
K	40.5	54.9	45.63	19.44	53.84	31.37
Soil Quality Index						
0.67(good)						

Table 2: Rice Productivity in Relation to Soil Nutrient-Supplying Capacity in Farmers' Fields During *Kharif* 2022: Nutrient Requirement per Tonne of Grain Yield

Farmers categories	Chinsurah			Titabar (total of 40 sites, 31 low yielders and 9 high yield sites)		
	Mean yield (t/ha)	Mean uptake (kg/ha)	Nutrient Requirement (kg/t grain)	Mean yield (t/ha)	Mean uptake (kg/ha)	Nutrient Requirement (kg/t grain)
Low Yielders (12 sites)	2.38	-	-	2.48	-	-
N		-	-		-	-
P		-	-		-	-
K		-	-		-	-
High Yielders (34 sites)	4.73	-	-	3.43	-	-
N		-	-		-	-
P		-	-		-	-
K		-	-		-	-
Farmers categories	Kanpur			Pantnagar		
	Mean yield (t/ha)	Mean uptake (kg/ha)	Nutrient Requirement (kg/t grain)	Mean yield (t/ha)	Mean uptake (kg/ha)	Nutrient Requirement (kg/t grain)
Low yielders	4.76			4.83		
N		77.57	16.29		40.17	8.31
P		28.13	5.90		4.93	1.02
K		9.30	1.95		29.81	5.96
High yielders	6.59			5.84		
N		113.93	17.28		47.8	8.18
P		44.59	6.76		8.58	1.46
K		14.93	2.26		28.69	4.92

Farmers categories	Kaul			Karaikal			
	Mean yield (t/ha)	Mean uptake (kg/ha)	Nutrient Requirement (kg/t grain)	Farmers categories	Mean yield (t/ha)	Mean uptake (kg/ha)	Nutrient Requirement (kg/t grain)
Low yielders	1.44				3.83		
N		30.4	21.11			26.83	7.01
P		11.3	7.84			15.12	3.94
K		35.4	24.5			30.12	7.84
High yielders	8.8				4.36		
N		114.5	13.01			33.83	7.75
P		42.09	4.78			16.68	3.82
K		45.63	5.18			31.37	7.19

Table 3: Rice Productivity in Relation to Soil Nutrient-Supplying Capacity in Farmers' Fields During *Kharif* 2022: Site-Specific Fertilizer Recommendations for Target Yield

Site/centres.	Current yield low yielders group (t/ha)	Current yield High Yielders group (t/ha)	Percent increase in yield over low yielders groups	Fertilizer recommendation for the target yield (t/ha) Chinsurah-5 Titabar-4.75 7.4, Karaikal-4.65 Kaul-9.9, Kanpur-7.18		
				N (Urea)	P ₂ O ₅ (SSP)	K ₂ O (Potash)
Chinsurah	2.38	4.73	49.7	90	25	50
Titabar	2.48	3.43	27.7	85	23	47
karaikal	3.83	4.36	12.2	32	18	36
Pantnagar	4.83	5.84	17.3	62	8	44
Kaul	1.44	8.8	83.6	114	42	45
Kanpur	4.76	6.59	27.8	119	42	16

Conclusion

The study demonstrated substantial variability in soil nutrient-supplying capacity, nutrient uptake and rice productivity among farmers' fields across the selected locations. The differences between low-and high-yielding fields resulted in considerable yield gaps, with the largest gap recorded at Kaul. Soil quality indices also varied among locations, indicating differences in overall soil fertility and productivity potential. The observed mismatch between soil-test values, nutrient uptake and grain yield highlights the limitations of relying solely on generalized fertilizer recommendations under diverse flooded rice conditions. Site-specific fertilizer prescriptions based on soil nutrient supply, crop nutrient uptake and nutrient requirement per unit of grain yield can therefore provide a more effective approach for improving nutrient-use efficiency and reducing yield gaps. The study emphasizes the importance of field-specific nutrient management for enhancing rice productivity while maintaining soil quality and long-term sustainability.

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