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Krishna Chaitanya A
Scientist, AICRP on LTFE,
RARS, Jagtial, PJTAU,
Telangana, India

Venu Reddy Challa
Research Associate, AICRP on
LTFE, RARS, Jagtial, PJTAU,
Telangana, India

Ravi P
Scientist, AICRP on LTFE,
RARS, Jagtial, PJTAU,
Telangana, India

Integrated phosphorus management in Rice (*Oryza sativa* L.): Effect on soil properties, nutrient dynamics, yield and economic returns in Telangana

Krishna Chaitanya A, Venu Reddy Challa and Ravi P

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Abstract

Phosphorus (P) is the second most limiting macronutrient in rice production systems of Telangana, yet blanket fertilizer recommendations often result in over- or under-application. This on-farm study evaluated the effect of integrated phosphorus management (IPM), based on Soil Health Card (SHC) recommendations combined with organic inputs, against conventional farmer practice (FP) in irrigated rice (*Oryza sativa* L.) during the yasangi (rabi) season 2020–21 in Jagtial district, Telangana. Ten farmers at Arpelli village, Sarangapoor mandal, participated in the demonstration. Initial soil analysis indicated slightly alkaline soils (mean pH 7.69), low to medium organic carbon (mean 0.50%) and low available phosphorus (mean 53 kg P ha⁻¹). IPM plots received site-specific P doses based on SHC integrated with organic manure, whereas FP plots followed traditional indiscriminate fertilizer application. Grain yield under IPM (mean 5733 kg ha⁻¹) and FP (mean 5832 kg ha⁻¹) were statistically similar ($p = 0.299$). However, straw yield differed significantly between treatments ($p = 0.039$), with FP recording a higher mean straw yield (6348 kg ha⁻¹) compared to IPM (6125 kg ha⁻¹). Nutrient content and uptake of N, P and K in plant tissue at panicle initiation showed no significant differences, except for P uptake at harvest ($p = 0.027$), where FP was higher. Notably, straw P content under IPM was significantly lower than FP ($p = 0.016$), suggesting more efficient P translocation to grain. Despite comparable grain yields, IPM recorded a superior mean benefit–cost (B:C) ratio (1.97) compared to FP (1.82), demonstrating better economic efficiency through reduced fertilizer input costs. These findings support the adoption of SHC-guided integrated nutrient management for sustainable, economically viable rice production in Telangana.

Keywords: Integrated phosphorus management, Soil Health Card, rice, nutrient uptake, benefit–cost ratio

1. Introduction

Rice (*Oryza sativa* L.) is the staple cereal crop of Telangana, cultivated across approximately 1.8 million hectares annually across kharif and yasangi seasons. In the Northern Telangana Zone (NTZ), irrigated rice under the yasangi season occupies a dominant position in the cropping calendar, supported by canal and reservoir irrigation. Sustaining productivity of this system demands balanced and site-specific nutrient management.

Phosphorus (P), the second most critical macronutrient for rice after nitrogen, plays central roles in energy transfer (ATP), root development, tillering and grain filling. Phosphorus deficiency markedly restricts yield in alkaline-calcareous soils where P fixation is prevalent (Dobermann and Fairhurst, 2000) [7]. In Telangana soils, a significant proportion of irrigated rice areas are characterised by low to medium available P status with 61% of Indian soils reported to be low in P (Bhatta *et al.*, 2021) [3] yet farmers eepersistently apply P at uniform rates without soil testing, resulting in both economic loss and environmental loading (Srinivasarao *et al.*, 2014) [16].

Studies have demonstrated that SHC-based fertilizer management can sustain crop yields while reducing excess P application by 15–25% compared to blanket recommendations (Vanlauwe *et al.*, 2010; Kishore *et al.*, 2021) [18, 11]. However, adoption of SHC recommendations at the farmer level remains partial, with surveys indicating that only 41% of SHC recipients actually follow the prescribed practices, with education, gender and market access being key determinants (Pandit *et al.*, 2025) [15].

Integrated nutrient management (INM) approaches, combining inorganic fertilizers with organic

Corresponding Author:
Krishna Chaitanya A
Scientist, AICRP on LTFE,
RARS, Jagtial, PJTAU,
Telangana, India

manures, further improve P use efficiency through enhanced microbial activity and organic acid production that solubilise soil-fixed P (Bhattacharyya *et al.*, 2008; Anantha *et al.*, 2024) ^[4, 1]. Meta-analyses of site-specific nutrient management (SSNM) across Asia and Africa have demonstrated that SSNM consistently increases rice grain yield by approximately 12% and profitability by 15% relative to farmer practice, with 10% less fertilizer nitrogen applied, thereby improving nutrient use efficiency (Chivenge *et al.*, 2021) ^[5]. Farmyard manure (FYM) application is particularly beneficial in low-P soils by reducing phosphate sorption and increasing P concentration in the soil solution. Long-term INM studies in rice systems have further confirmed that combined NPK and FYM application yields the highest benefit–cost ratio and improves soil carbon status over time (Das *et al.*, 2024) ^[6].

Despite their agronomic and economic merits, SHC-guided integrated phosphorus management (IPM) practices remain underutilised at the farmer level in Telangana due to limited awareness, knowledge gaps, and perceived risk of yield reduction. On-farm demonstrations that compare IPM with existing farmer practice under actual field conditions are

essential to build evidence and farmer confidence.

The present study was therefore undertaken during the yasangi (rabi) season 2020–21 at Arpelli village, Sarangapoor mandal, Jagtial district, Telangana, with the objectives of: (i) Evaluating the effect of Integrated Phosphorus management versus farmer practice on crop nutrient content and uptake at panicle initiation and harvest stages; (ii) comparing grain and straw yield; and (iii) assessing the economic returns through benefit–cost analysis.

2. Materials and Methods

2.1 Study Site and Farmer Selection

The study was conducted during the yasangi (rabi irrigated) season, October 2020 to February 2021, at Arpelli village, Sarangapoor mandal, Jagtial district, Telangana (approximately 18°52'N, 78°56'E; altitude ~280 m amsl). The region has a semi-arid tropical climate with mean annual rainfall of 900–950 mm, predominantly received during the kharif season. Ten farmers (Table 1) with comparable field sizes and similar management history were selected through purposive sampling in consultation with local agricultural extension staff.

Table 1: Details of farmers participating in the integrated phosphorus management demonstration, Arpelli village, Sarangapoor mandal, Jagtial district, Telangana, Yasangi 2020–21.

S. No.	Name of the Farmer	Address
1	Pranay Thota S/O Gangaram	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
2	Gangaram Thota S/O Bhumalingu	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
3	Thota Jayakar S/O Bhumalingu	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
4	Basamalla Babaiah S/O Buchiramulu	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
5	Endapetla Kishore S/O Venkati	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
6	Thota Vajra S/O Anandam	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
7	Pachunuri Maheswari W/O Shekar	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
8	Reddy Thirupathi S/O Ganga Reddy	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
9	J. Linga Reddy	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial
10	Thota Rajaiah S/O Lachaiah	Vil. Arpelli, Man. Sarangapoor, Dist. Jagtial

2.2 Initial Soil Sampling and Analysis

Prior to transplanting, composite soil samples (0–20 cm depth) were collected from each farmer's field using a soil sampling auger. Each composite sample comprised 10–12 sub-samples collected in a zig-zag pattern across the plot. Samples were air-dried, ground, and passed through a 2-mm sieve. Standard laboratory procedures were followed: soil pH and EC were measured in 1:2.5 soil–water suspension using a digital pH metre and conductivity metre, respectively (Jackson, 1973) ^[10]; organic carbon (OC) by the Walkley–Black wet oxidation

method (Walkley.A, 1947) ^[20]; available nitrogen (N) by the alkaline permanganate method (Subbiah and Asija, 1956) ^[17]; available phosphorus (P) by the Olsen method using NaHCO₃ extractant (Olsen *et al.*, 1954) ^[14]; and available potassium (K) by flame photometry after ammonium acetate extraction (Jackson, 1973) ^[10]. Soil organic carbon was rated according to the critical limits established for Indian soils, and available P and K were interpreted using criteria validated for Telangana soils (Krishnamurthy *et al.*, 2024) ^[12].

Table 2: Physico-chemical properties of initial soil samples from participating farmers' fields, Yasangi 2020–21

S.no	pH	EC (dSm ⁻¹)	OC (%)	Avail. N (kg ha ⁻¹)	Avail. P (kg ha ⁻¹)	Avail. K (kg ha ⁻¹)
1	7.72	0.52	0.45	192	32.40	326
2	7.84	0.39	0.51	205	73.80	286
3	7.64	0.46	0.53	153	62.30	310
4	7.82	0.28	0.50	136	73.00	262
5	7.69	0.47	0.48	142	82.00	196
6	7.38	0.31	0.62	162	42.00	206
7	7.68	0.45	0.52	181	38.00	234
8	7.91	0.38	0.38	155	29.00	216
9	7.55	0.35	0.42	167	45.00	227
10	7.62	0.37	0.55	174	51.00	186
Mean	7.69	0.40	0.50	167	53	245

2.3 Treatment Details

Each participating farmer implemented both treatments on comparable, adjacent plots within their holding. Integrated

Phosphorus Management (IPM): Phosphorus fertilizer dose was determined individually for each field based on Soil Health Card (SHC) recommendations, with P rates adjusted according to

initial available P status. All fields received farmyard manure (FYM) at 5 t ha⁻¹ as basal application to improve organic matter and enhance P availability. FYM application has been shown to substantially reduce P sorption in calcareous soils, increasing P concentration in the soil solution and improving P use efficiency, particularly in fields with low initial P status. Nitrogen and potassium were applied uniformly at recommended rates (120 kg N ha⁻¹ and 60 kg K₂O ha⁻¹) across all IPM plots, with N split into three equal doses (basal, active tillering, panicle initiation).

Farmer Practice (FP)

Farmers applied fertilizers according to their customary practice without soil test guidance. The FP plots received no organic manure. Fertilizer quantities and splitting patterns were recorded for each farmer.

2.4 Plant Sampling and Nutrient Analysis

Plant samples (whole tillers) were collected at panicle initiation (PI) stage and at harvest from five representative spots per plot. At harvest, grain and straw fractions were separated. All samples were oven-dried at 65°C to constant weight and ground to fine powder. Plant nutrient content (N, P, K) was determined after tri-acid (HNO₃:H₂SO₄: HClO₄) wet digestion. Nitrogen was estimated by micro-Kjeldahl distillation, phosphorus by the vanado-molybdate yellow colour method spectrophotometrically, and potassium by flame photometry (AOAC, 2000) [2]. Nutrient uptake (kg ha⁻¹) was calculated as the product of dry matter yield and nutrient content (Irfan *et al.*, 2020) [9].

2.5 Yield and Economic Analysis

Grain and straw yields (kg ha⁻¹) were recorded at physiological maturity from a 5 m × 5 m area per plot. The benefit–cost (B:C) ratio was calculated using prevailing market prices during 2020–21: paddy grain at ₹1,868 per quintal (MSP, GoI), urea at ₹266.50 per bag (45 kg), SSP at ₹350 per bag (50 kg), MOP at ₹850 per bag (50 kg), and FYM at ₹1,500 per tonne. Total input costs included seed, irrigation, plant protection, labour and fertilizer/manure costs.

2.6 Statistical Analysis

Data from the ten paired farmer fields were analysed using a paired-samples t-test to compare IPM and farmer practice within each field (treatment as within-subject factor).

3. Results and Discussion

3.1 Initial Soil Physico-Chemical Properties

The initial soil chemical analysis of the ten participating fields is presented in Table 2. Soil pH ranged from 7.38 to 7.91 with a mean of 7.69, indicating slightly alkaline reaction, which is characteristic of the black cotton (Vertisol) and mixed red-and-black soils of Northern Telangana. Electrical conductivity ranged from 0.28 to 0.52 dS m⁻¹ (mean 0.40 dS m⁻¹), well below the salinity threshold for rice (4 dS m⁻¹) and posing no salinity

constraint.

Organic carbon content ranged from 0.38 to 0.62% (mean 0.50%), falling in the medium category (0.50–0.75%) as per the Walkley–Black scale. Low OC in intensively cropped rice fields of Telangana has been widely documented and is attributed to rapid mineralisation of crop residues under warm, humid conditions, stubble removal, and intensive tillage (Srinivasarao *et al.*, 2014) [16]. Farming scenario studies on Vertisol-based rice systems have further confirmed that conventional tillage without organic inputs significantly depresses soil OC, available N, P, and K compared to integrated nutrient management (Mishra *et al.*, 2024) [13]. Soil organic matter level directly influences P availability through competition between humic acids and phosphate ions for sorption sites, and through stimulation of P-solubilising microbial communities (Bhattacharyya *et al.*, 2008; Dutta *et al.*, 2024) [4, 8].

Available nitrogen ranged from 136 to 205 kg ha⁻¹ (mean 167 kg ha⁻¹), placing most fields in the low to medium N category. Available phosphorus ranged from 29.0 to 82.0 kg ha⁻¹ (mean 53 kg ha⁻¹), spanning low (fields 1, 8), medium (fields 2, 3, 4, 6, 7), and high (field 5) categories according to the critical limits established for Telangana soils (Velayutham *et al.*, 1999) [19]. This spatial variability in soil P status across neighbouring fields underscores the inadequacy of blanket P recommendations and validates the SHC-based field-specific IPM approach. Nationally, over 61% of Indian agricultural soils have been reported to be deficient in available P, reinforcing the need for routine soil testing as the basis for fertilizer decisions (Bhatta *et al.*, 2021) [3]. Available potassium ranged from 186 to 326 kg ha⁻¹ (mean 245 kg ha⁻¹), indicating medium to high K status, consistent with the K-rich nature of black soils in the region.

3.2 Effect of IPM on Grain and Straw Yield, and Benefit–Cost Ratio

The grain yield, straw yield, and B:C ratio under IPM and FP are presented in Table 3. Mean grain yield and stover yield under IPM (5733 kg ha⁻¹) (6125 kg ha⁻¹) was not significantly different from FP (5832 kg ha⁻¹; *p* = 0.299) (6348 kg ha⁻¹), indicating that the SHC-guided P management, despite using lower or more precisely calibrated P doses, maintained yield parity with conventional over-application. This finding is consistent with earlier on-farm studies across Andhra Pradesh and Telangana demonstrating that balanced, site-specific fertilizer management sustains yields without sacrificing productivity (Bhattacharyya *et al.*, 2008; Srinivasarao *et al.*, 2014) [4, 16].

Straw yield, however higher under FP (6348 kg ha⁻¹) compared to IPM (6125 kg ha⁻¹). The higher straw biomass under FP is likely attributable to the generally higher P applications promoting vegetative tissue development. Excess P availability can stimulate shoot growth through enhanced photosynthate allocation to straw (Dobermann and Fairhurst, 2000) [7]. Nevertheless, the higher straw yield under FP did not translate into significantly higher grain yield, suggesting differential assimilate partitioning rather than greater total productivity.

Table 3: Effect of Integrated phosphorus management on Dry matter production (kg ha⁻¹) and yield of paddy crop (Kg ha⁻¹) during Rabi, 2020-21

S. No.	Grain yield (kg ha ⁻¹)		Straw yield (kg ha ⁻¹)		B:C ratio	
	IPM	Farmer practice	IPM	Farmer practice	IPM	Farmer practice
1	5591	5641	6140	6411	1.90	1.68
2	5914	6165	6145	6649	2.07	1.89
3	5414	5392	5887	6130	1.81	1.68
4	4915	5064	5392	5589	1.55	1.53
5	5592	5665	6140	6142	1.90	1.81

6	6142	6418	6421	6491	2.18	2.10
7	5665	5672	5914	6146	1.94	1.69
8	6142	6287	6425	6649	2.18	2.02
9	5814	5841	6142	6412	2.01	1.80
10	6147	6175	6649	6865	2.19	1.95
Mean	5733	5832	6125	6348	1.97	1.82
P value (t-test)<0.05	0.298661		0.088995		0.038809	

The B:C ratio was higher under IPM (mean 1.97) than under FP (mean 1.82). This economic advantage accrued principally because IPM plots required lower expenditure on P fertilizers (SSP/DAP), since soil test-based doses were often lower for medium- to high-P fields, while grain yield was sustained. Long-term INM studies in rice systems have confirmed that combined NPK and FYM application consistently achieves B:C ratios above 2.0, outperforming mineral fertilizer alone in economic terms (Das *et al.*, 2024) [6]. Similarly, Chivenge *et al.* (2021) [5] reported a global average 15% improvement in profitability under SSNM relative to farmer practice across rice, wheat and maize cropping systems. The economic advantage of IPM is particularly relevant in the Telangana context, where input costs are a key constraint for small and marginal farmers.

3.3 Plant Nutrient Content and Uptake at Panicle Initiation Stage

Plant nutrient content (N, P, K) and uptake at the panicle initiation (PI) stage are presented in Tables 4 and 5, respectively. Mean N content was 0.89% under IPM and 0.88% under FP ($p = 0.249$, NS). Similarly, K content (IPM: 1.41%; FP: 1.42%) was

statistically similar ($p = 0.411$, NS). Plant P content at PI was comparable between IPM (0.14%) and FP (0.15%), with a near-significant trend ($p = 0.062$). Mean N uptake at PI was 31.37 kg ha⁻¹ under IPM and 31.70 kg ha⁻¹ under FP ($p = 0.432$, NS). Phosphorus uptake at PI tended to be lower under IPM (4.78 kg ha⁻¹) than FP (5.32 kg ha⁻¹; $p = 0.056$, NS). Potassium uptake was statistically similar (IPM: 49.7; FP: 51.3 kg ha⁻¹; $p = 0.262$, NS).

These results indicate that P nutrition at the critical panicle initiation stage was adequately maintained under IPM despite lower P fertilizer inputs. Adequate P nutrition at PI is critical for panicle emergence, spikelet differentiation, and grain filling (Dobermann and Fairhurst, 2000) [7]. The comparable P uptake between IPM and FP at PI suggests that FYM application under IPM enhanced P availability sufficiently to compensate for lower inorganic P input, consistent with the documented role of organic manure in reducing P sorption in alkaline soils and improving P recovery by the crop. The beneficial effect of FYM on P nutrition under SSNM has also been demonstrated through enhanced lowland paddy P use efficiency when Azolla and straw are combined with balanced mineral fertilisation.

Table 4: Effect of Integrated phosphorus management on major nutrient content of rice plants at panicle initiation stage during yasangi, 2020-21

Plant Nutrient Content (%) at Panicle Initiation Stage						
S. No.	N (%)		P (%)		K (%)	
	IPM	Farmer practice	IPM	Farmer practice	IPM	Farmer practice
1	0.90	0.86	0.12	0.13	1.35	1.29
2	0.88	0.85	0.15	0.14	1.38	1.45
3	0.81	0.83	0.15	0.14	1.42	1.44
4	0.92	0.88	0.13	0.12	1.48	1.51
5	0.82	0.85	0.16	0.19	1.42	1.45
6	0.91	0.86	0.12	0.15	1.35	1.36
7	0.94	0.99	0.14	0.16	1.43	1.44
8	0.95	0.92	0.12	0.14	1.55	1.51
9	0.91	0.89	0.13	0.15	1.34	1.38
10	0.86	0.82	0.14	0.15	1.39	1.34
Mean	0.89	0.88	0.14	0.15	1.41	1.42
P value (t-test)<0.05	0.249290		0.061926		0.410990	

Table 5: Effect of Integrated phosphorus management on major nutrient uptake of rice plants at panicle initiation stage during yasangi, 2020-21

Plant Nutrient uptake (kg ha ⁻¹) at Panicle Initiation Stage						
S. No.	N (kg ha ⁻¹)		P (kg ha ⁻¹)		K (kg ha ⁻¹)	
	IPM	Farmer practice	IPM	Farmer practice	IPM	Farmer practice
1	25.7	26.9	3.42	4.06	38.5	40.3
2	31.4	31.1	5.35	5.12	49.2	53.0
3	26.4	27.6	4.88	4.66	46.2	47.9
4	28.8	29.3	4.06	3.99	46.3	50.2
5	26.7	27.8	5.21	6.21	46.2	47.4
6	35.9	33.1	4.73	5.78	53.3	52.4
7	33.7	37.1	5.02	5.99	51.3	53.9
8	37.6	36.9	4.74	5.62	61.3	60.6
9	33.6	33.4	4.79	5.63	49.4	51.8
10	34.1	33.8	5.55	6.19	55.1	55.3
Mean	31.37	31.70	4.78	5.32	49.7	51.3
P value (t-test)<0.05	0.432303		0.056175		0.262076	

3.4 Nutrient Content and Uptake in Grain and Straw at Harvest

Nutrient content in grain and straw at harvest is presented in Tables 6 and 7. Mean grain N content was virtually identical between IPM (1.02%) and FP (1.03%; $p = 0.303$, NS). Grain P content was similarly comparable (IPM: 0.19%; FP: 0.20%; $p =$

0.303, NS). Grain K content showed no significant difference (IPM: 0.39%; FP: 0.41%; $p = 0.135$, NS). These data confirm that IPM plots achieved equivalent grain nutrient quality to FP, which is agronomically important from both a crop productivity and nutritional quality perspective.

Table 6: Effect of Integrated phosphorus management on major nutrient content of rice grain at harvesting stage during Yasangi, 2020-21

Plant Nutrient Content (%) of grain at harvesting stage						
S. No.	N (%)		P (%)		K (%)	
	IPM	Farmer practice	IPM	Farmer practice	IPM	Farmer practice
1	1.04	1.11	0.22	0.24	0.37	0.40
2	0.95	0.95	0.19	0.21	0.42	0.47
3	0.98	1.00	0.18	0.19	0.31	0.34
4	1.03	1.01	0.15	0.17	0.39	0.39
5	0.98	1.04	0.18	0.20	0.42	0.41
6	0.95	0.99	0.21	0.22	0.41	0.43
7	1.04	1.06	0.19	0.21	0.38	0.39
8	1.10	1.11	0.17	0.17	0.45	0.46
9	1.11	1.02	0.18	0.17	0.39	0.41
10	0.97	0.99	0.19	0.18	0.38	0.41
Mean	1.02	1.03	0.19	0.20	0.39	0.41
P value (t-test)<0.05		0.303361	0.303361		0.134846	

Straw N content was comparable (IPM: 0.56%; FP: 0.57%; $p = 0.337$, NS). Straw P content was significantly lower under IPM (0.13%) compared to FP (0.14%; $p = 0.016$), indicating that the

higher P application in FP resulted in greater P accumulation in straw rather than in grain. Straw K was not significantly different (IPM: 1.36%; FP: 1.39%; $p = 0.183$, NS).

Table 7: Effect of Integrated phosphorus management on major nutrient content of rice straw at harvesting stage during yasangi, 2020-21

Plant Nutrient Content (%) of straw at harvesting stage						
S. No	N (%)		P (%)		K (%)	
	IPM	Farmer practice	IPM	Farmer practice	IPM	Farmer practice
1	0.48	0.5	0.12	0.13	1.34	1.36
2	0.61	0.59	0.12	0.14	1.42	1.48
3	0.58	0.59	0.11	0.12	1.42	1.44
4	0.59	0.61	0.14	0.15	1.41	1.42
5	0.54	0.56	0.16	0.14	1.34	1.36
6	0.52	0.55	0.14	0.16	1.28	1.31
7	0.53	0.51	0.11	0.13	1.26	1.32
8	0.54	0.53	0.13	0.16	1.38	1.34
9	0.61	0.62	0.12	0.14	1.34	1.36
10	0.57	0.59	0.12	0.15	1.44	1.51
Mean	0.56	0.57	0.13	0.14	1.36	1.39
P value (t-test)<0.05		0.337387	0.016224		0.183187	

At harvest, mean total N uptake (grain + straw) was 92.3 kg ha⁻¹ under IPM and 95.8 kg ha⁻¹ under FP ($p = 0.114$, NS). Phosphorus uptake at harvest was significantly lower under IPM (18.5 kg ha⁻¹) compared to FP (20.5 kg ha⁻¹; $p = 0.027$). Potassium uptake at harvest was 106.0 (IPM) vs. 112.4 kg ha⁻¹ (FP; $p = 0.066$, NS). The significantly lower total P uptake under IPM driven primarily by lower straw P content while maintaining equivalent grain yield and grain P content is agronomically desirable. It implies that IPM facilitated more efficient translocation of absorbed P into grain relative to straw, reducing surplus P retention in crop residues.

This finding is consistent with the phosphorus harvest index (PHI) concept, whereby cultivars or management systems with lower straw P concentration simultaneously improve PHI and grain yield by enhancing P translocation into grain, thereby reducing the need for P fertilizer application (Irfan *et al.*, 2020) [9]. Tissue-specific P allocation studies in rice have demonstrated that rice cultivars with high internal remobilisation capacity

accumulate less P in straw and redirect it to grain, a trait associated with high P use efficiency (Irfan *et al.*, 2020; Bhatta *et al.*, 2021) [9, 3]. The current data suggest that the SHC-guided IPM approach, by avoiding P over-supply, elicited a similar response at the agronomy level: plants under IPM were more efficient in utilising absorbed P for grain development rather than accumulating excess P in straw tissue.

Furthermore, soil P dynamics in alkaline soils are strongly influenced by organic matter content. Long-term INM studies have shown that combined organic–inorganic P management improves the bioavailable P pool in alkaline Fluvisols and Vertisols, reducing P fixation and sustaining crop P nutrition across seasons (Dutta *et al.*, 2024) [8]. The P dynamics reported here are thus consistent with a system where FYM-driven improvements in OC and microbial activity under IPM compensate for lower inorganic P inputs, sustaining crop P nutrition while reducing total P removal in straw.

Table 8: Effect of Integrated phosphorus management on major nutrient uptake (kg ha⁻¹) of rice plants at harvest stage during Yasangi, 2020-21

S. No.	Plant Nutrient uptake at harvesting					
	N (kg ha ⁻¹)		P (kg ha ⁻¹)		K (kg ha ⁻¹)	
	IPM	Farmer practice	IPM	Farmer practice	IPM	Farmer practice
1	87.6	94.7	19.7	21.9	103.0	109.7
2	93.7	97.8	18.6	22.3	112.1	127.4
3	87.2	90.1	16.2	17.6	100.4	106.6
4	82.4	85.2	14.9	17.0	95.2	99.1
5	88.0	93.3	19.9	19.9	105.8	106.8
6	91.7	99.2	21.9	24.5	107.4	112.6
7	90.3	91.5	17.3	19.9	96.0	103.2
8	102.3	105.0	18.8	21.3	116.3	118.0
9	102.0	99.3	17.8	18.9	105.0	111.1
10	97.5	101.6	19.7	21.4	119.1	129.0
Mean	92.3	95.8	18.5	20.5	106.0	112.4
P value (t-test)<0.05	0.114178		0.026608		0.065907	

4. Conclusion

This on-farm study demonstrated that integrated phosphorus management based on Soil Health Card recommendations combined with farmyard manure application maintained rice grain and straw yield at par with conventional farmer practice in Jagtial district, Telangana, during the yasangi season 2020–21. Integrated Phosphorus management (IPM) achieved significantly a superior benefit–cost ratio (1.97 vs. 1.82), underscoring the economic advantage of soil test-based P application. A significantly lower straw P content and total P uptake at harvest under IPM without compromising grain P content or yield indicates more efficient internal P use, consistent with an improved phosphorus harvest index under the IPM approach.

References

- Anantha KC, Penjarla R, Challa VR, Bairi R, Kurella CS, Gokenapally S, *et al.* Phosphorus transformation and balancing under a long-term rice-rice cropping system in an inceptisol of India. *Journal of Plant Nutrition*. 2024;47(18):3035-3050.
- AOAC. Official methods of analysis of AOAC International. 17th ed. Gaithersburg, MD: AOAC International; 2000.
- Bhatta BB, Panda RK, Anandan A, Pradhan NSN, Mahender A, Rout KK, *et al.* Improvement of phosphorus use efficiency in rice by adopting image-based phenotyping and tolerant indices. *Frontiers in Plant Science*. 2021;12:717107.
- Bhattacharyya R, Kundu S, Prakash V, Gupta HS. Sustainability under combined application of mineral and organic fertilizers in a rainfed soybean-wheat system of the Indian Himalayas. *European Journal of Agronomy*. 2008;28(1):33-46.
- Chivenge P, Saito K, Bunquin MA, Sharma S, Dobermann A. Co-benefits of nutrient management tailored to smallholder agriculture. *Global Food Security*. 2021;30:100570.
- Das B, Bhattacharyya R, Bhatt R, Yadav B, Singh AK, Bisht JK, *et al.* Long-term assessment of diverse nutrient management strategies in a rice-rice cropping system: analysing yield trends, resource use efficiency and economic viability over a sixteen-year period. *Journal of Plant Nutrition*. 2024;47(6):905-925.
- Dobermann A, Fairhurst TH. Rice: nutrient disorders and nutrient management. Manila: International Rice Research Institute; 2000.
- Dutta A, Hazra KK, Nath CP, Kumar N, Singh SS, Praharaj CS. Long-term impact of legume-inclusive diversification and nutrient management practices on phosphorus dynamics in alkaline Fluvisol. *Scientific Reports*. 2024;14:65.
- Irfan M, Aziz T, Maqsood MA, Bilal HM, Siddique KHM, Xu M. Phosphorus use efficiency in rice is linked to tissue-specific biomass and P allocation patterns. *Scientific Reports*. 2020;10:4278.
- Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
- Kishore A, Alvi M, Krupnik TJ. Development of balanced nutrient management innovations in South Asia: perspectives from Bangladesh, India, Nepal, and Sri Lanka. *Global Food Security*. 2021;28:100464.
- Krishnamurthy R, Bhavya N, Govinda K, Basavaraja PK, Uday Kumar SN, Mohamed Saqueebulla H, *et al.* Soil test crop response nutrient prescription equations for improving soil health and yield sustainability: a long-term study under Alfisols of southern India. *Frontiers in Plant Science*. 2024;15:1439523.
- Mishra AK, Maurya PK, Sharma S. Impact of different farming scenarios on key soil sustainability indicators driving soil carbon and system productivity of rice-based cropping systems. *Frontiers in Plant Science*. 2024;15:1408515.
- Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. Washington, DC: United States Department of Agriculture; 1954.
- Pandit NR, Thapa G, Gaihre YK, Choudhary D, Rusinamhodzi L. Farmers' response to soil health card recommendations: input usage and crop yield. *Nutrient Cycling in Agroecosystems*. 2025;131:473-486.
- Srinivasarao C, Venkateswarlu B, Lal R, Singh AK, Kundu S, Vittal KPR, *et al.* Long-term manuring and fertilizer effects on depletion of soil organic carbon stocks under pearl millet-cluster bean-castor rotation in Western India. *Land Degradation and Development*. 2014;25(2):173-183.
- Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. 1956;25:259-260.
- Vanlauwe B, Bationo A, Chianu J, Giller KE, Merckx R, Mokuwye U, *et al.* Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*. 2010;39(1):17-24.
- Velayutham M, Mandal DK, Mandal C, Sehgal J. Agro-

- ecological sub-regions of India for planning and development. Technical Bulletin No. 50. Nagpur: National Bureau of Soil Survey and Land Use Planning; 1999.
20. Walkley A. A critical examination of a rapid method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science*. 1947;63(4):251-264.