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Optimizing Potassium Nutrition through Integrated Soil and Foliar Application for Sustained Rice Productivity in New Alluvial Zone of West Bengal

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ABSTRACT

Potassium (K) is a key nutrient governing rice productivity, water relations, and stress tolerance, yet its management in intensive rice-based systems is often inadequate or inefficient. Imbalanced fertilization and insufficient potassium (K) application continue to threaten the sustainability of intensive rice production in the NAZ (New Alluvial zone) of West Bengal. A three-year field experiment (2022–2024) was conducted during the *Kharif* season at the Water Management Research Station (WMRS), Ranaghat, Nadia, West Bengal, to evaluate the effect of integrated soil and foliar potassium management on yield, nutrient uptake, soil fertility, and economics of rice (*Oryza sativa* L.). The experiment was laid out in a randomized complete block design (RCBD) with seven treatments and three replications, combining varying levels of soil-applied K through complex fertilizers (NPK:10:26:26) and or muriate of potash (MOP) as straight one with inorganic K sprays and sole organic treatment as bioslurry-based nutrition including foliar organic K spray. Pooled analysis demonstrated that the highest grain yield (6.01 t/ha) and superior Benefit-Cost (B:C) ratio 1.36 were achieved by treatment with 100% NPK of recommended dose of fertilizer (RDF) combined with twice-inorganic foliar K sprays. Notably, treatment with 100% NP + 75% K of RDF + twice-inorganic K spray yielded a statistically comparable 5.70 t/ha, suggesting that K use efficiency can be enhanced by substituting 25% of basal soil K with foliar applications. The foliar treatments also significantly reduced the percentage of chaffy grains in treatment with 100% NP & 75% K @ RDF + two times spraying of KNO_3 @ 2% (17.05%) against control i.e., only RDF (22.34%) which indicating improved grain filling. While organic treatment (100% Bio-slurry) yielded lower but remained statistically at par with control (only RDF) and it exhibited significant improvements in soil available micronutrients and organic carbon. The findings confirm that integrated K management, particularly supplementing basal fertilization with foliar sprays, is the optimal strategy for maximizing both productivity and profitability in this region.

Keywords: Rice, Foliar K Spray, NAZ (New Alluvial zone), INM, Bio-slurry

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Introduction

In the intensive agricultural landscape of West Bengal's New Alluvial Zone, maintaining soil fertility while maximizing crop yield is a primary challenge. Potassium management is frequently overlooked compared to nitrogen and phosphorus, leading to nutrient imbalances and increased susceptibility to water stress.

Rice is the staple food for more than half of the world's population and plays a central role in food and nutritional security of India. In eastern India, particularly West Bengal, intensive rice cultivation under irrigated conditions has resulted in progressive depletion of soil potassium reserves due to imbalanced fertilizer use, removal of crop residues, and high yield targets. Although many alluvial soils are classified as medium to high in available K, continuous cropping has led to emerging K deficiencies, often hidden or marginal, which limit yield response to nitrogen and phosphorus.

Potassium is involved in enzyme activation, photosynthate translocation, stomatal regulation, and osmotic balance, thereby directly influencing plant water uptake, drought tolerance, and grain filling in rice. As Muriate of Potash (MOP) is imported, it is the most expensive component for farmers as a source of soil potassium. Hence farmer depends on complex fertilizers for supplying potassium which are easier to handle and often more available, however, these fertilizer provide K in fixed ratios that may not meet the high demands of modern rice varieties.

Constant "K mining" i.e. removing more K through harvest than is applied has led to widespread soil deficiencies (Ramamurthy *et al.*, 2017; Vijayakumar *et al.*, 2023). Recent reviews by Vijayakumar (2021 and 2023) show that 41% of Indian soil samples are now low in available K. Soil application builds the reserve, while foliar spray provides immediate availability during peak demand stages like panicle initiation. Recent studies have emphasized that reliance solely on soil-applied K may not be sufficient under high-yielding systems, especially during peak demand stages such as tillering and panicle initiation (Mohapatra *et al.*, 2025). Foliar application of K offers a rapid and efficient means of supplying K during critical growth stages, improving nutrient-use efficiency and mitigating temporary soil constraints. Study conducted by El-Sherpiny, M. A. (2022) suggest that foliar application of liquid potassium is an efficient alternative to MOP allowing farmers to reduce their reliance on expensive soil fertilizers while maintaining high crop growth and yield. However they did not consider the K mining factor.

Integrated nutrient management (INM), combining inorganic fertilizers, organic sources, and foliar nutrition, is increasingly recognized as a sustainable strategy to maintain soil health while achieving high productivity as depicted by Chatterjee, S. and Bandyopadhyay, K. K. (2022). Organic amendments such as bio-slurry not only supply nutrients but also enhance soil organic carbon and micronutrient availability. However, systematic information on long-term integrated K management involving complex fertilizers, foliar sprays, and organic sources under the recent alluvial soils of West Bengal is limited.

Keeping in the backdrop high cost of potassic fertilizer, reduction of the quantity of soil potassic fertilizer application and use of organic nutrient as sole source for sustaining soil health, the present investigation aims to evaluate the effect of integrated soil and foliar K application on rice yield and yield attributes, assess long-term soil health under changing climatic conditions, plant K uptake and analyze the economic viability of different K management strategies.

Materials and Methods

Present field experiment was conducted in the *kharif* season (warmer rainy season, June to October, 2022, 2023 and 2024) in the Agricultural Demonstration Farm, Water Management Research Station, Ranaghat, Nadia, located at latitude of 88.56° E and longitude of 23.15° N to evaluate seven distinct Potassium nutrient management strategies on yield, yield attributing characters, K uptake of rice variety *Pratiksha* and soil health parameters. Seven treatments were tested in randomized block design with three replicates each in a 3m x 5m size plot keeping 20 cm x 15 cm plant spacing. Rice crop was grown with NP fertilizers as per state recommendation and varying level of Potassium management. The detailed treatments tested in the present experiment are given in Table 1.

Table 1. **Treatment details of the experiment**

Treatments	Detailed Protocol
T_1	100% NPK @ RDF (recommended dose of fertilizer) + Inorganic K spray (KNO_3 @2%) –Twice
T_2	100% NP & 75% K @ RDF + Inorganic K spray(KNO_3 @2%) - Twice
T_3	100% NP 50 % K @ RDF + Inorganic K spray (KNO_3 @2%) - Twice
T_4	100% NP 25% K @ RDF + Inorganic K spray (KNO_3 @2%) - Twice
T_5	100% NP 0% K @ RDF + Inorganic K spray - (KNO_3 @2%) -Thrice
T_6	100% NPK @ RDF
T_7	100 % Bio-slurry + Organic K spray (Tri potassium citrate @2%)-Twice

NB: T_1-T_2: Application of basal K through Complex fertilizer (10:26:26) and top dressing through MOP, T_3-T_4 : Application of basal K through Complex fertilizer (10:26:26), T_6: Application of K through straight fertilizer MOP. K foliar spray twice at 21 DAT and 42 DAT for T_1- T_4 and $T_{7\,;}$ K foliar spray thrice at 21 DAT , 42 DAT and 75 DAT for T_5.

Initial soil samples prior to onset of the experiment were being collected at the beginning of the experiment during May, 2022. For estimating physicochemical properties soil samples were collected at a depth of 0-15 cm, brought to the laboratory, dried in shade, ground to pass through 2 mm sieve and immediately assayed for physicochemical properties. Soil reaction (pH) was determined using soil: water ratio 1:2 by potentiometric method (Jackson, 1973), OC by chromic acid digestion method (Walkley and Black, 1934); available K_2O by neutral normal ammonium acetate extraction method (Jackson, 1973), available P_2O_5 by Olsen's method (Olsen *et al.*, 1954), DTPA extracted available Zn was measured through atomic absorption spectrophotometer by Lindsay and Norvell (1969) method , available SO_4-S extraction by $CaCl_2$ turbidity method, Chesnin and Yien (1951) and $CaCl_2$ extractable boron Berger and Troug (1939) was measured spectrophotometrically using azomethane reagent. Rice grain and straw sample were digested overnight by diacid mixture followed by K estimation through Flame photometer. The soil (0-15 cm) of the experimental plot was of alluvial in origin, sandy loam in texture, having electrical conductivity (EC) of 0.38 dS m^{-1}, neutral in reaction (pH 7.37) with 0.42% organic carbon (OC), available nitrogen 170 kg/ha, available P_2O_5 82.46 kg/ha available K_2O 235 kg/ha, available sulphur 18.52 ppm, available Zn and B 0.58 and 0.47 mg kg^{-1}, respectively. Initial soil status report shows that soil potassium and phosphorus level is medium, organic carbon and nitrogen level is low, sulphur level is high, soil is zinc deficient and soil boron level is above critical level. Fertilizer doses for N:P:K @ 2.5-5.0-5.0 g/m^2 as basal and N @ 2.5 g/m^2 as top dressing in the form of urea, single superphosphate and muriate of potash, respectively was being applied after hand weeding at 15 days interval of seed sowing in the nursery bed. Hydro-primed seed was sown in the nursery bed @ 50g/m^2. Soil test based fertilizer doses recommended for the region (N:P:K @ 80:40:40 kg ha^{-1}) was used to supply inorganic nutrients in the form of urea, single superphosphate, muriate of potash and N:P:K 10:26:26. Full and P doses and varying level of K fertilizers were used accordingly. The treatments consisted of different combinations of soil-applied K through complex fertilizer (10:26:26) or MOP, foliar application of inorganic K (KNO_3), organic K (K-citrate), and bio-slurry @ 7.5 t/ha in 3 splits (50% at basal and 25% each at 15 and 35DAT). Foliar sprays were applied at 21 and 42 days after transplanting (DAT), while in one treatment an asdditional spray was applied at 75 DAT.

One fourth of N, full P and K were applied as basal (before transplanting) followed by ½ N at tillering stage and rest N (1/4) at panicle initiation (PI) stage for the respective treatment plots. However, treatment T_1, T_2 and T_6 received top dressing of K in the form of MOP.

Growth Attributes and Yields of Rice

Yield attributing characters such as plant height (cm), nos. of productive tillers per plant, panicle length (cm), nos. of filled grains per panicle and test weight (g) were measured by harvesting ten plant samples per plot selected at random. At maturity plant samples were collected for estimation of grain and straw potassium and the rice crop was harvested for recording grain and straw yield.

Statistical Analysis

Statistical analysis of all the soil and plant data derived from the plots in the experiment was performed following the analysis of variance (ANOVA) test, using the SPSS (IBM SPSS Statistics, Version 19) software package and the mean values were compared by DMRT (p≤0.05) as per the methods suggested by Gomez and Gomez (1984).

Results and Discussion

Initial Soil Fertility Status of the Experimental Site

The experimental soil was neutral in reaction (pH 7.37) with low electrical conductivity (0.378 dS m^{-1}), indicating non-saline conditions conducive to rice cultivation. Organic carbon content was moderate (0.42%), while available phosphorus (82.46 kg ha^{-1}) and potassium (235.0 kg ha^{-1}) were in the medium fertility range. Micronutrients such as zinc (0.58 ppm) and boron (0.47 ppm) were marginal to adequate, whereas available sulphur (18.52 ppm) was sufficient. These baseline soil conditions are typical of intensively cultivated rice ecosystems and provide a suitable framework to evaluate the response of rice to integrated soil and foliar potassium management (Dobermann *et al.*, 2022).

Effect of Integrated Soil and Foliar Potassium Application on Soil Chemical Properties

Integrated potassium management did not significantly influence soil pH, EC, organic carbon, or available phosphorus across treatments (Table 2), suggesting that varying K application strategies did not disrupt overall soil chemical equilibrium. Similar observations have been reported in medium-term nutrient management studies in rice, where potassium primarily affects soil exchangeable K pools without altering bulk soil chemical properties (Li *et al.*, 2024).

Significant differences were observed for available soil potassium, boron, and sulphur. The highest available K_2O content was recorded in treatment T_1 (100% NPK @ RDF + inorganic K spray twice), indicating that balanced fertilization combined with foliar supplementation effectively replenished soil K reserves. Progressive reduction of basal potassium (T_2–T_5) resulted in a corresponding decline in available soil K, highlighting the limitation of foliar sprays in sustaining soil K pools when soil application is inadequate. These findings corroborate recent reports emphasizing that foliar potassium primarily addresses short-term crop demand but cannot substitute for soil-applied K in maintaining long-term soil fertility (Römheld and Kirkby, 2023).

The organic treatment (T_7: 100% bio-slurry + organic K spray) recorded higher organic carbon, available boron, and sulphur, reflecting the beneficial role of organic amendments in enhancing secondary and micronutrient availability through improved microbial activity and nutrient mineralization (Saha *et al.*, 2022). This underscores the added soil health benefits of organic nutrient sources beyond potassium supply alone.

Effect on Yield Attributes, Grain Yield, and Economics

Integrated potassium management significantly influenced yield attributes and grain yield of rice (Table 3). The lowest percentage of chaffy grains and the highest grain yield were recorded under T_1, producing 5.91 t ha^{-1} during 2024 and a pooled mean yield of 6.01 t ha^{-1} over three years. Adequate potassium availability is known to enhance assimilate translocation, grain filling, and spikelet fertility, thereby reducing chaffiness and improving yield (Zörb *et al.*, 2022).

Treatments T_2 (75% soil K + foliar sprays) and T_3 (50% soil K + foliar sprays) produced yields statistically comparable to T_1, suggesting that partial substitution of basal potassium with foliar application can maintain productivity without significant yield loss. This finding aligns with recent studies demonstrating improved potassium use efficiency when soil and foliar K applications are synchronized with crop demand (Wang *et al.*, 2024). However, treatments with minimal or no soil-applied K (T_4 and T_5) resulted in significantly lower yields, indicating that foliar sprays alone are insufficient to meet crop potassium requirements under intensive rice cultivation.

The organic treatment (T_7) recorded a lower pooled yield (4.92 t ha^{-1}) but remained statistically at par with T_6 (100% NPK without foliar K). Although grain yield under organic management was lower than the best integrated treatment, it remained comparable to conventional fertilization without foliar potassium, suggesting that organic inputs can partially substitute mineral fertilizers while contributing positively to soil health. Similar yield equivalence between organic and inorganic nutrient sources has been reported under integrated nutrient management systems in rice (Choudhary *et al.*, 2023).

Economic analysis revealed the highest benefit–cost ratio under T_1 (1.36), followed by T_2, T_3, and T_6, indicating that balanced fertilization with foliar K supplementation is not only agronomically superior but also economically viable. These results are consistent with recent economic assessments advocating balanced nutrient management to maximize returns while minimizing input costs (Sharma *et al.*, 2024).

Potassium Uptake by Grain and Straw

Potassium uptake by grain and straw differed significantly among treatments (Table 4). The highest K uptake by grain (18.9 kg ha^{-1}) and straw (67.6 kg ha^{-1}) was recorded under T_1, reflecting improved K availability and enhanced uptake efficiency under balanced fertilization. Treatments T_2 and T_3 were statistically comparable to T_1, confirming that moderate reduction in soil K can be compensated through foliar supplementation in terms of plant K nutrition.

Lower potassium uptake under T_4, T_5, and T_7 indicates restricted K availability and reduced uptake efficiency, which ultimately translated into lower yields. Potassium plays a critical role in enzyme activation, stomatal regulation, and assimilate transport; therefore, inadequate K supply directly limits biomass accumulation and grain yield (Hafsi *et al.*, 2022). The present findings reinforce the importance of maintaining adequate soil potassium reserves alongside foliar supplementation for sustained nutrient uptake and productivity.

Conclusion

Balanced fertilization with 100% NPK combined with foliar K sprays is the most effective strategy for sustaining high rice yields (6.01 t/ha) under intensive cultivation. Partial substitution of soil K @ 25% with foliar sprays may be recommended without significant yield reduction (5.70 t/ha), offering scope for nutrient use efficiency and fertilizer cost reduction. Overall, the findings underlined that an integrated potassium management method combining balanced soil fertilization with targeted foliar supplementation offers a viable pathway to promote nutrient usage efficiency, sustain rice yield, and improve economic returns. Adoption of such integrated strategies can support resource-efficient and environmentally sustainable rice cultivation, particularly under intensive cropping systems where potassium depletion is a growing concern.

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Table 2. Effect of integrated soil and foliar potassium application on soil chemical properties after harvest

Treatment	pH	EC (dS m^{-1})	Org. C (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Zn (ppm)	B (ppm)	S (ppm)
T1	7.34	0.31	0.42	78.67	217.7	0.58	0.407	16.14
T2	7.39	0.32	0.43	79.33	206.7	0.55	0.403	15.78
T3	7.34	0.26	0.45	77.67	183.0	0.58	0.377	16.58
T4	7.36	0.30	0.40	78.00	166.7	0.55	0.397	15.93
T5	7.26	0.33	0.42	81.00	161.7	0.61	0.390	15.99
T6	7.27	0.35	0.42	76.67	203.7	0.56	0.393	16.04
T7	7.23	0.32	0.49	82.67	179.3	0.63	0.496	21.66
SEM (±)	0.056	0.027	0.018	2.33	3.59	0.03	0.018	0.684
CD (P=0.05)	NS	NS	NS	NS	11.20	NS	0.055	2.13

Table 3. Effect of integrated soil and foliar potassium application on rice yield, chaffy grain percentage, and economics

Treatment (%)	Chaffy grains	Grain yield 2024 (t ha^{-1})	Pooled grain yield (t ha^{-1})	B:C ratio
T1	17.31^{bc}	5.91^{a}	6.01^{a}	1.36
T2	17.05^{c}	5.87^{a}	5.70^{ab}	1.30
T3	20.76C^{abc}	5.59^{ab}	5.61^{b}	1.29
T4	20.15C^{abc}	5.06^{c}	5.04^{c}	1.17
T5	21.13C^{a}	5.26^{bc}	5.14^{c}	1.16
T6	22.34C^{a}	5.30^{bc}	5.19^{c}	1.26
T7	20.93^{ab}	4.94^{c}	4.92^{c}	1.02
SEM (±)	0.814	0.143	0.113	–
CD (P=0.05)	2.54	0.45	0.32	–

Note: **Values followed by different superscript letters within a column differ significantly at P = 0.05.**

Table 4. Effect of integrated soil and foliar potassium application on potassium uptake by rice

Treatment	K uptake by grain (kg ha^{-1})	K uptake by straw (kg ha^{-1})
T1	18.9^{a}	67.6^{a}
T2	17.6^{ab}	66.6^{a}
T3	17.9^{ab}	67.0^{a}
T4	13.1^{d}	61.2^{ab}
T5	15.8^{bc}	60.8^{ab}
T6	14.8^{cd}	60.6^{ab}
T7	12.9^{d}	55.0^{b}
SEM (±)	0.73	2.16
CD (P=0.05)	2.28	8.14

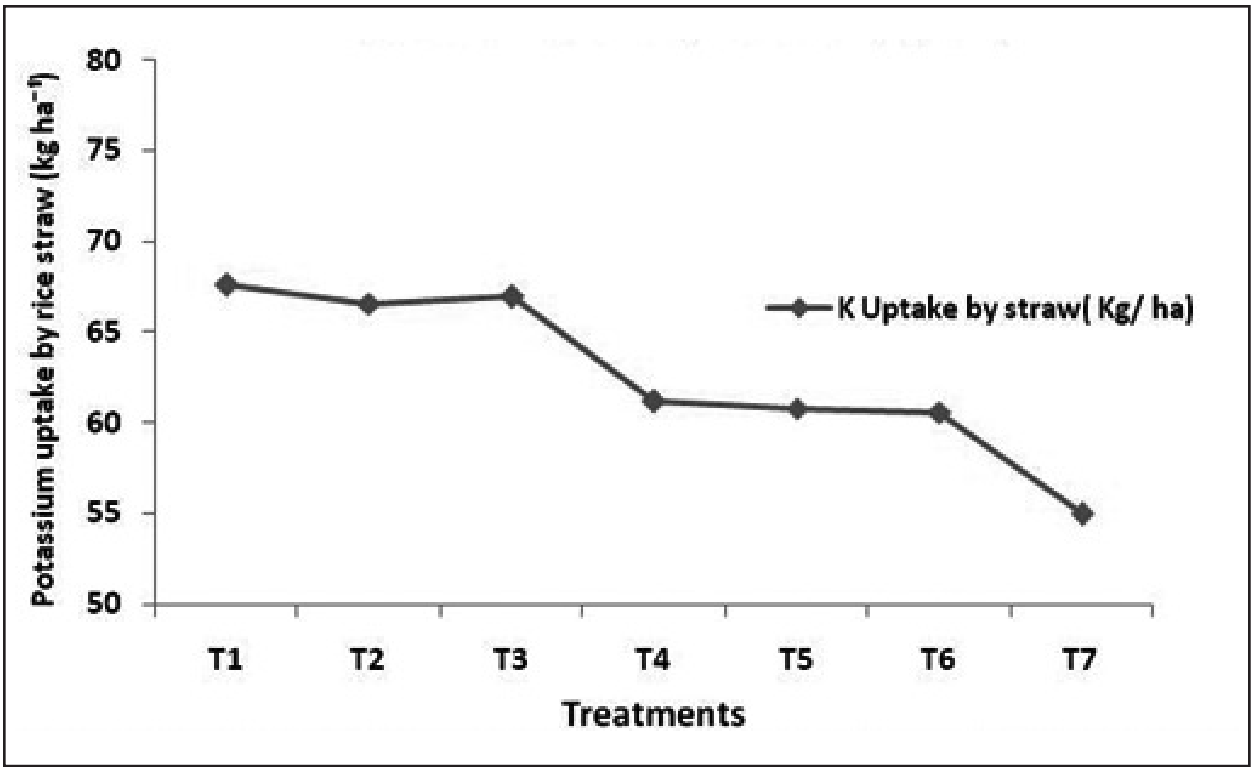

Figure 1. Effect of integrated soil and foliar potassium management on potassium uptake by rice straw (kg ha^{-1}).