



## Potassium Use Efficiency of Modern Rice Variety Influenced by Integrated Nutrient Management Options in Dry Season

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### Abstract

Potassium (K) is a major nutrient limiting productivity of modern rice varieties, yet its efficient utilization remains a challenge under intensive cultivation. A field experiment was conducted during the 2021–22 and 2022–23 dry (Boro) seasons at Sher-e-Bangla Agricultural University to evaluate potassium uptake and use efficiency of BRRI dhan100 under integrated nutrient management. Seven fertilizer treatments, including recommended practice, increased or reduced K levels, soil-test-based fertilization, cowdung incorporation, and control, were arranged in a randomized complete block design with three replications. Grain yield, yield components, nutrient uptake, and K use efficiency indices were measured. Integrated nutrient management with cowdung (K5) consistently produced the highest grain yield ( $6.75 \text{ t ha}^{-1}$ ) and improved yield attributes across both seasons. Treatments receiving balanced K fertilization showed higher K uptake and efficiency compared with K-deficient plots. Agronomic efficiency and recovery efficiency were notably enhanced under integrated nutrient supply. Results indicate that combining inorganic fertilizers with organic amendments improves potassium use efficiency, sustains soil fertility, and enhances productivity of modern rice. Therefore, integrated nutrient management involving recommended fertilizer dose plus cowdung is suggested for sustainable cultivation of BRRI dhan100 during the Boro season.

**Keywords:** Agronomic, recovery, physiological and internal efficiency; partial factor productivity, potassium harvest index.

### INTRODUCTION

Rice (*Oryza sativa* L.) is the primary staple food for more than half of the global population and plays a crucial role in global food security and rural livelihoods [1, 2]. According to Food and Agriculture Organization, rice is cultivated on over 160 million hectares worldwide, producing more than 750 million tons annually [3, 4]. In Bangladesh, rice dominates the agricultural sector, occupying about 75% of total cropped area and contributing substantially to national food supply and farm income [5, 6]. Despite remarkable progress in varietal development and crop management, average rice yield in Bangladesh remains lower than that of major rice-producing countries due to nutrient imbalances, soil fertility decline, and inefficient fertilizer use.

Potassium (K) is one of the three primary macronutrients required in large quantities for rice growth and productivity [7, 8, 9, and 10]. It plays key physiological roles in enzyme activation, photosynthesis, osmotic regulation, assimilate transport, and stress tolerance. Adequate potassium supply enhances resistance to lodging, pests, and diseases, improves grain filling, and increases yield stability [9].

Rice crops typically remove 100–300 kg K ha<sup>-1</sup> per season, yet K fertilization in many rice-growing areas is often inadequate relative to crop removal, leading to soil K depletion and declining productivity [11, 12]. Continuous intensive cropping, use of high-yielding varieties, and limited recycling of crop residues further aggravate potassium deficiency in South Asian soils. Improving potassium use efficiency (KUE) has therefore become essential for sustainable rice production [13, 14, 15]. Integrated nutrient management (INM), combining inorganic fertilizers with organic amendments such as cowdung or compost, has been widely recommended to enhance nutrient availability, improve soil physical properties, and increase fertilizer efficiency. Organic amendments can increase cation exchange capacity, reduce nutrient losses, stimulate microbial activity, and enhance K availability from non-exchangeable soil pools. However, information on KUE of modern high-yielding rice varieties under different integrated nutrient management options during the dry (Boro) season remains limited [3].

Modern rice varieties developed by Bangladesh Rice Research Institute have higher yield potential but also greater nutrient demand.

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Efficient nutrient management strategies are therefore required to achieve high productivity without degrading soil health. Understanding potassium uptake dynamics and use efficiency under different fertilization strategies will help optimize fertilizer recommendations and improve sustainability of rice-based systems [16,17,18].

Therefore, the present study was conducted to evaluate the growth performance, yield, potassium uptake, and potassium use efficiency of a modern rice variety under different fertilizer management options, including recommended practice, soil-test-based fertilization, and integrated nutrient management during the Boro season. The findings are expected to provide guidance for improving potassium management and sustaining rice productivity in intensive rice-growing regions.

## Materials and Methods

### Study Site

The experiment was conducted during the Boro seasons of 2022 and 2023 at the research field of Sher-e-Bangla Agricultural University, located in Dhaka. The site belongs to the Agro-Ecological Zone (AEZ-28, Madhupur Tract) and is characterised by subtropical monsoon climate with mild winter and hot, humid summer.

The experiment was carried out on typical rice-growing silty clay loam soil at the Soil Science Farm of Sher-e-Bangla Agricultural University. Surface soil samples (0–20 cm depth) were collected before land preparation and analysed for physicochemical properties. The soil contained 18.60% sand, 45.40% silt, and 36.00% clay, with a pH of 6.8, organic matter 1.38%, total N 0.06%, available P 19.85 mg kg<sup>-1</sup>, exchangeable K 0.12 meq 100 g<sup>-1</sup>, and available S 14.40 mg kg<sup>-1</sup>.

### Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Plot size was 3 m × 4 m, and plots were separated by 0.5 m bunds.

Seven potassium management treatments were evaluated using the rice variety BRRI dhan100:

**I. K1:** Recommended fertiliser dose (PR): N-P-K-S-Zn @ 124-22-75-20-4 kg ha<sup>-1</sup>

**II. K2:** K1 + 33% additional K

**III. K3:** K1 – 33% K

**IV. K4:** K1 without potassium (–K)

**V. K5:** K1 + cowdung @ 5 t ha<sup>-1</sup>

**VI. K6:** Soil test-based fertilisation (STB): N-P-K-S-Zn @ 130-24-83-22-3 kg ha<sup>-1</sup>

**VII. K7:** Absolute control (no fertiliser)

Fertiliser sources included urea for N, triple superphosphate for P, muriate of potash for K, gypsum for S, and zinc sulfate for Zn. Cowdung was well-decomposed before application.

### Crop Establishment and Management

Seeds of BRRI dhan100 were sown in well-prepared wet nursery beds on 11 December 2021 and 7 December 2022. Thirty-five-day-old seedlings were transplanted on 26 January 2022 and 13 January 2023 at 25 cm × 15 cm spacing with 2–3 seedlings per hill.

Cowdung was incorporated 20 days before transplanting. The full doses of P, K, S, and Zn were applied during final land preparation, while nitrogen from urea was applied in three equal splits at 15, 30, and 45 days after transplanting. Standard agronomic practices including irrigation, weeding, and plant protection were applied uniformly across treatments.

The crop was harvested at physiological maturity when approximately 85–90% of grains turned golden yellow. A central harvest area of 6 m<sup>2</sup> per plot was used to determine grain and straw yields. Grain yield was adjusted to 14% moisture content and straw yield to 3% moisture.

### Plant Sampling and Nutrient Analysis

Grain and straw samples were oven-dried, ground, and analysed for potassium content. Digested samples were diluted to a known volume, and potassium concentration was determined using a flame photometer. Nutrient uptake was calculated by multiplying nutrient concentration with corresponding biomass yield.

### Potassium Use Efficiency Indices

Potassium use efficiency indices were calculated using standard equations:

#### Partial Factor Productivity of K (PFPK)

$$PFP_K (\text{kg kg}^{-1}) = GY_{+K} / FK [18]$$

#### Agronomic Efficiency of K (AEK)

$$AE_K (\text{kg kg}^{-1}) = (GY_{+K} - GY_{0K}) / FK [18]$$

#### Recovery Efficiency of K (REK)

$$RE_K = (UK_{+K} - UK_{0K}) / FK [18]$$

#### Physiological Efficiency of K (PEK)

$$PE_K (\text{kg kg}^{-1}) = (GY_{+K} - GY_{0K}) / (UN_{+K} - UN_{0K}) [18,19]$$

#### Internal Efficiency of K (IEK)

$$IE_K = GY / UK [19]$$

#### Potassium Harvest Index (KHI)

$$NHI = GK / TK [18,19,20]$$

where  $GY_{+K}$  and  $GY_{0K}$  are grain yields with and without potassium,  $F_K$  is applied potassium,  $U_{+K}$  and  $U_{0K}$  are potassium uptake with and without fertiliser,  $G_K$  is grain potassium uptake, and  $T_K$  is total plant potassium uptake.

### Statistical Analysis

Data were analysed using analysis of variance (ANOVA) appropriate for RCBD. Treatment means were separated using Least Significant Difference (LSD) at 5% probability level [21]. Statistical analyses were performed using Statistix 10.

### Experimental Validity

The experiment was repeated across two consecutive years to ensure reproducibility and minimise seasonal variability. Uniform crop management and randomisation were maintained to reduce experimental error.

## Results and Discussion

### Effect of Potassium Levels on Growth and Yield Components

Growth and yield-contributing characters of BRRI dhan100 were significantly influenced ( $p < 0.01-0.05$ ) by different potassium (K) management strategies in both Boro seasons (Table 1). Plant height increased markedly with K fertilisation compared with the control (K7), indicating improved vegetative growth under balanced nutrition. The tallest plants were observed in soil test-based fertilisation (K6) in both 2022 (102.65 cm) and 2023 (103.45 cm), whereas the shortest plants occurred in the unfertilised control. Adequate potassium improves cell elongation, enzyme activation, and photosynthetic efficiency, leading to greater biomass accumulation.

The number of tillers  $m^{-2}$  also increased significantly with K application. Maximum tillering was recorded in K6 (2022) and K5 (2023), while K7 produced the fewest tillers. Potassium enhances nitrogen uptake and carbohydrate metabolism, which supports tiller formation and survival. Similar responses of tiller production to potassium fertilisation were reported by earlier studies.

Panicle number  $m^{-2}$  followed a similar pattern, with K5 and K6 producing significantly more panicles than the control. Improved tiller survival and nutrient availability likely contributed to higher panicle density. Panicle length and grains panicle $^{-1}$  were also significantly increased by K fertilisation, with the highest values recorded in K5 or K6 treatments. Potassium plays an important role in assimilate transport and spikelet differentiation, which enhances panicle development and grain set.

Conversely, unfilled spikelets panicle $^{-1}$  and sterility percentage were highest in the control treatment and lowest in K5 and K6. Adequate potassium improves pollen viability, grain filling, and plant resistance to stress, thereby reducing sterility. Fertility percentage showed the opposite trend, confirming improved reproductive success under balanced fertilisation. However, 1000-grain weight was not significantly affected, suggesting that potassium mainly influenced grain number rather than individual grain size.

Overall, these results demonstrate that balanced potassium supply significantly improves vegetative growth, panicle development, and grain formation, ultimately enhancing yield potential.

**Table 1. Effect of different K levels on growth and yield attributes of BRRI Dhan100 during the 2022 and 2023 dry (Boro) season rice at SAU Dhaka, Bangladesh**

Treatment	Plant height (cm)	Tillers $m^{-2}$ (no.)	Panicles $m^{-2}$ (no.)	Panicle length (cm)	Grains panicle $^{-1}$ (no.)	Fertility (%)	Sterility (%)	1000-grain wt. (g)
<i>2022 Dry Season</i>								
N <sub>1</sub>	102.05 a	281 b	259 b	25.63 a	107 a	25 ab	80.77 ab	19.23 b
N <sub>2</sub>	100.12 a	311 a	288 a	25.23 a	105 a	25 ab	80.77 ab	19.23 b
N <sub>3</sub>	99.85 a	283 b	261 b	25.88 a	101 b	26 ab	79.53 ab	20.47 b
N <sub>4</sub>	98.65 a	236 c	212 c	21.45 b	81 c	24 ab	77.14 b	22.86 b
N <sub>5</sub>	101.67 a	319 a	291 a	26.23 a	113 a	22 b	83.70 a	16.30 c
N <sub>6</sub>	102.65 a	325 a	285 a	26.65 a	106 a	23 b	82.17 a	17.83 c
N <sub>7</sub>	83.23 b	229 c	206 c	21.14 b	78 c	29 a	72.90 c	27.10 a
LSD <sub>(0.05)</sub>	9.76	18.43	18.45	2.16	8.23	5.42	4.56	2.09
F-test	0.05	0.01	0.01	0.01	0.01	0.01	0.05	0.01
<i>2023 Dry Season</i>								
N <sub>1</sub>	101.56 a	284 b	261 b	25.56 a	102 b	24 a	80.95 ab	19.05 bc
N <sub>2</sub>	99.67 a	306 a	285 a	25.92 a	103 b	23 b	81.75 ab	18.25 c
N <sub>3</sub>	100.34 a	294 b	271 b	25.68 a	103 b	24 a	81.10 ab	18.90 c
N <sub>4</sub>	99.62 a	238 c	216 c	22.14 b	84 c	23 b	78.50 b	21.50 b
N <sub>5</sub>	100.78 a	324 a	294 a	27.02 a	115 a	22 b	83.33 a	16.67 d
N <sub>6</sub>	103.45 a	322 a	281 ab	26.95 a	110 ab	24 a	82.09 a	17.91 d
N <sub>7</sub>	82.65 b	225 c	211 c	21.56 b	71 c	27 a	72.45 c	27.55 a
LSD <sub>(0.05)</sub>	11.05	15.34	16.78	2.24	11.27	3.34	3.78	3.56
F-test	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Means within a column with similar letter(s) were statistically identical, whereas different letter(s) differed significantly at  $p < 0.01$  and  $p < 0.05$ .

### Grain, Straw, and Biological Yield

Grain, straw, and biological yields were significantly affected by potassium management in both years (Table 2). The highest grain yield was consistently recorded in K5 (6.68 t ha $^{-1}$  in 2022 and 6.75 t ha $^{-1}$  in 2023), followed by K1 and K6. The lowest yield occurred in the unfertilised control.

Yield improvement under K fertilisation can be attributed to increased tiller number, panicle density, grains panicle $^{-1}$ , and reduced sterility. Potassium improves photosynthetic rate, assimilate transport, and enzyme activation, which enhance both grain and straw yield [22,23]. The addition of cowdung in K5 further improved soil structure, microbial activity, and nutrient availability, resulting in superior performance compared with mineral fertiliser alone.

Straw and biological yields followed trends similar to grain yield, indicating improved overall plant growth [24]. Harvest index was also higher in fertilised treatments compared with the control, reflecting improved partitioning of biomass toward grain production.

These findings confirm that potassium fertilisation, particularly when integrated with organic manure, significantly increases productivity of modern rice varieties.

**Table 2. Effect of different K levels on grain, straw and biological yields; and harvest index of BRRI dhan100 during Boro 2022 and 2023 at SAU Dhaka, Bangladesh**

Treatment	Grain yield (t ha $^{-1}$ )	Straw yield (t ha $^{-1}$ )	Biological yield (t ha $^{-1}$ )	Harvest index (%)
<i>2022 Dry Season</i>				
N <sub>1</sub>	6.39 a	6.78 a	13.17 a	48.52 a
N <sub>2</sub>	5.96 b	6.45 a	12.41 a	48.03 a
N <sub>3</sub>	5.13 c	5.82 ab	10.95 b	46.85 a
N <sub>4</sub>	5.05 c	5.48 b	10.53 b	47.96 a
N <sub>5</sub>	6.68 a	7.04 a	13.72 a	48.69 a
N <sub>6</sub>	6.26 ab	6.87 a	13.13 a	47.68 a
N <sub>7</sub>	3.51 d	4.67 c	8.18 c	42.91 b
LSD <sub>(0.05)</sub>	0.61	0.62	0.71	2.89
F-test	0.01	0.01	0.01	0.05
<i>2023 Dry Season</i>				
N <sub>1</sub>	6.49 a	6.91 a	13.40 a	48.43 a
N <sub>2</sub>	5.89 b	6.78 a	12.67 b	46.49 a
N <sub>3</sub>	5.21 c	5.96 b	11.17 c	46.64 a
N <sub>4</sub>	4.96 c	5.53 b	10.49 c	47.28 a
N <sub>5</sub>	6.75 a	7.07 a	13.82 a	48.84 a
N <sub>6</sub>	6.31 ab	6.89 a	13.20 a	47.80 a
N <sub>7</sub>	3.49 d	4.73 c	8.22 d	42.46 b
LSD <sub>(0.05)</sub>	0.45	0.7	1.03	2.16
F-test	0.01	0.01	0.01	0.05

In a column means with similar letter(s) were statistically identical and those having dissimilar letter(s) differed significantly at  $p < 0.01$  and  $p < 0.05$ .

### Nutrient Content and Uptake

Nutrient concentrations in grain were significantly influenced by fertiliser treatments (Table 3). Grain N, P, K, and S contents were higher in fertilised treatments than in the control, indicating improved nutrient uptake efficiency. The highest nutrient uptake was generally observed in K5 and K6 treatments, reflecting higher biomass production and better nutrient availability. Potassium fertilisation enhances root growth, membrane permeability, and enzyme activity, facilitating uptake of other nutrients such as nitrogen and phosphorus. Increased nutrient concentration in grain suggests improved nutritional quality and efficient nutrient utilization[25]. These results are consistent with previous reports that balanced fertilisation improves both yield and nutrient uptake in rice.

**Table 3. Effect of treatments on N, P, K and S content by grain of BRRI dhan100 during 2022 and 2023 dry (Boro) season at SAU Dhaka, Bangladesh**

Treatment	N content in grain (%)	P content in grain (%)	K content in grain (%)	K uptake by grain (kg t <sup>-1</sup> )	S content in grain (%)
<i>2022 Dry Season</i>					
N <sub>1</sub>	1.43 a	0.196 a	0.151 a	96.49 a	0.126 a
N <sub>2</sub>	1.51 a	0.191 a	0.156 a	92.98 a	0.129 a
N <sub>3</sub>	1.20 b	0.195 a	0.132 b	67.72 b	0.128 a
N <sub>4</sub>	1.13 b	0.191 a	0.121 bc	61.11 b	0.121 a
N <sub>5</sub>	1.43 a	0.202 a	0.148 a	98.86 a	0.126 a
N <sub>6</sub>	1.54 a	0.199 a	0.143 ab	89.52 a	0.128 a
N <sub>7</sub>	0.53 c	0.153 b	0.115 c	40.37 c	0.082 b
LSD <sub>(0.05)</sub>	1.59	0.03	0.01	7.35	0.07
F-test	0.01	0.01	0.01	0.01	0.01
<i>2023 Dry Season</i>					
N <sub>1</sub>	1.42 a	0.199 a	0.147 a	95.40 a	0.123 a
N <sub>2</sub>	1.42 a	0.193 a	0.159 a	93.65 a	0.127 a
N <sub>3</sub>	1.21 b	0.194 a	0.135 b	70.34 b	0.126 a
N <sub>4</sub>	1.24 b	0.196 a	0.117 bc	58.03 c	0.125 a
N <sub>5</sub>	1.42 a	0.205 a	0.146 a	98.55 a	0.129 a
N <sub>6</sub>	1.42 a	0.197 a	0.141 ab	88.97 a	0.124 a
N <sub>7</sub>	0.61 c	0.151 b	0.109 c	38.04 d	0.087 b
LSD <sub>(0.05)</sub>	1.35	0.03	0.02	9.12	0.08
F-test	0.01	0.01	0.01	0.01	0.01

Means within a column having similar letter(s) were statistically similar and those having different letter(s) differed significantly at  $p < 0.01$ .

### Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) indices were significantly affected by potassium management (Table 4). Partial factor productivity (FPF), agronomic efficiency (AE), recovery efficiency (RE), and physiological efficiency (PE) were highest in treatments with balanced fertilisation (K1, K3, K5, and K6), while unfertilised treatments showed minimal efficiency.

Improved NUE under potassium fertilisation may result from enhanced nitrogen assimilation, reduced nutrient losses, and better synchronisation of nutrient supply with crop demand. Potassium regulates stomatal function and enzyme activity, improving nitrogen metabolism and biomass production. These findings highlight the importance of balanced fertilisation for improving nutrient-use efficiency and sustainability of rice production.

**Table 4. Treatments effect on N use efficiencies of BRRI dhan100 during Boro 2022 and 2023 at SAU Dhaka, Bangladesh**

Treatments	FPF <sub>N</sub>	AE <sub>N</sub>	RE <sub>N</sub>	PE <sub>N</sub>	IE <sub>N</sub>	NHI
	(kg kg <sup>-1</sup> )	(kg kg <sup>-1</sup> )	(%)	(kg kg <sup>-1</sup> )	(kg kg <sup>-1</sup> )	(kg kg <sup>-1</sup> )
<i>2022 Dry Season</i>						
N <sub>1</sub>	85 b	38.40 a	1.24 a	37.60 b	66 c	0.50 a
N <sub>2</sub>	60 c	24.50 c	0.89 c	33.83 c	64 c	0.58 a
N <sub>3</sub>	103 a	32.40 b	1.28 a	42.05 a	76 ab	0.34 b
N <sub>4</sub>	0 d	0.00 d	0.00 d	0.00 d	83 a	0.09 c
N <sub>5</sub>	80 b	37.74 a	1.13 b	40.52 b	68 c	0.48 a
N <sub>6</sub>	67 c	29.57 b	0.92 c	44.76 a	70 b	0.55 a
N <sub>7</sub>	0 d	0.00 d	0.00 d	0.00 d	87 a	0.15 c
LSD <sub>(0.05)</sub>	7.44	4.01	0.056	3.45	4.68	0.06
F-test	0.01	0.01	0.01	0.01	0.01	0.01
<i>2023 Dry Season</i>						
N <sub>1</sub>	87 b	40.00 a	1.22 b	38.01 b	68 bc	0.51 a
N <sub>2</sub>	59 d	24.00 d	0.09 d	36.86 b	63 c	0.58 a
N <sub>3</sub>	104 a	34.40 b	1.33 a	38.08 b	74 b	0.33 c
N <sub>4</sub>	0 e	0.00 e	0.00 e	0.00 c	85 a	0.09 d
N <sub>5</sub>	80 b	38.81 a	1.13 c	38.67 b	68 bc	0.48 b
N <sub>6</sub>	68 c	30.32 c	0.91 d	42.41 a	71 b	0.55 a
N <sub>7</sub>	0 e	0.00 e	0.00 e	0.00 c	92 a	0.16 d
LSD <sub>(0.05)</sub>	7.83	2.89	0.038	4.35	6.9	0.07
F-test	0.01	0.01	0.01	0.01	0.01	0.01

Means within a column having similar letter(s) are statistically similar, whereas those with different letter(s) differ significantly at  $p < 0.01$ .

## Overall Interpretation

Across both experimental years, integrated nutrient management involving potassium fertiliser and organic manure (K5) or soil test-based fertilisation (K6) produced superior growth, yield components, grain yield, nutrient uptake, and nitrogen use efficiency compared with recommended practice or control treatments. The results indicate that potassium deficiency severely limits rice productivity, while balanced fertilisation enhances plant growth, reproductive development, and nutrient utilisation. Integration of organic manure further improves soil fertility and crop performance.

## Conclusion

The present study demonstrated that potassium management significantly influenced growth, yield components, nutrient uptake, and nitrogen use efficiency of BRRI dhan100 during two consecutive Boro seasons. Integrated nutrient management combining recommended fertiliser dose with cowdung (K5) and soil test-based fertilisation (K6) consistently produced superior plant growth, higher tiller and panicle density, improved grain fertility, reduced sterility, and maximum grain yield compared with conventional practice and unfertilised control.

Balanced potassium nutrition enhanced nutrient uptake (N, P, K, and S), improved nitrogen use efficiency, and increased harvest index, indicating more efficient biomass partitioning toward grain production. In contrast, omission of potassium severely reduced growth and yield, confirming that potassium deficiency is a major constraint to achieving high productivity in rice cultivation.

Overall, the results suggest that site-specific potassium fertilisation integrated with organic manure is an effective strategy for improving rice yield, nutrient-use efficiency, and soil fertility sustainability. Adoption of soil test-based potassium management can therefore enhance productivity of modern rice varieties while reducing nutrient imbalance and environmental risks.

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