Journal of Plant Biota

Original Research Article
ISSN: 3048-4863
Journal homepage: https://plant.researchfloor.org/

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

Chowdhury Md. Humayun Kabir[1], Alok Kumar Paul[2], Biswajit Karmakr[3], Israt Alam[4], and Khalid Syfullah*[5]

[1]*Ideal School and College, Motijheel, Dhaka-1000, Bangladesh*
[2]*Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh*
[3]*Bangladesh Rice Research Institute, Joydebpur,Gazipur, Bangladesh*
[4]*Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh*
[5]*Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh*

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 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^{-1} 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.

19 October 2025: Received | 16 November 2025: Revised | 20 December 2025: Accepted | 24 January 2026: Available Online

Citation: Chowdhury Md. Humayun Kabir, Alok Kumar Paul, Biswajit Karmakr, Israt Alam, Khalid Syfullah (2026). Potassium Use Efficiency of Modern Rice Variety Influenced by Integrated Nutrient Management Options in Dry Season. *Journal of Plant Biota.* **31 to 35. DOI: https://doi.org/10.51470/JPB.2026.5.1.31**

Khalid Syfullah | syfullahkhalid11@gmail.com

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 propertiesThe 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^{-1}, exchangeable K 0.12 meq 100 g^{-1}, and available S 14.40 mg kg^{-1}.

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^{-1}

II. K2: K1 + 33% additional K

III. K3: K1 – 33% K

IV. K4: K1 without potassium (–K)

V. K5: K1 + cowdung @ 5 t ha^{-1}

VI. K6: Soil test-based fertilisation (STB): N-P-K-S-Zn @ 130-24-83-22-3 kg ha^{-1}

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^2 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 (kg kg^{-1}) = GY_{+K}/FK [18]

Agronomic Efficiency of K (AEK)

AE_K (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 (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)
2022 Dry Season								
N_1	102.05 a	281 b	259 b	25.63 a	107 a	25 ab	80.77 ab	19.23 b
N_2	100.12 a	311 a	288 a	25.23 a	105 a	25 ab	80.77 ab	19.23 b
N_3	99.85 a	283 b	261 b	25.88 a	101 b	26 ab	79.53 ab	20.47 b
N_4	98.65 a	236 c	212 c	21.45 b	81 c	24 ab	77.14 b	22.86 b
N_5	101.67 a	319 a	291 a	26.23 a	113 a	22 b	83.70 a	16.30 c
N_6	102.65 a	325 a	285 a	26.65 a	106 a	23 b	82.17 a	17.83 c
N_7	83.23 b	229 c	206 c	21.14 b	78 c	29 a	72.90 c	27.10 a
$LSD_{(0.05)}$	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
2023 Dry Season								
N_1	101.56 a	284 b	261 b	25.56 a	102 b	24 a	80.95 ab	19.05 bc
N_2	99.67 a	306 a	285 a	25.92 a	103 b	23 b	81.75 ab	18.25 c
N_3	100.34 a	294 b	271 b	25.68 a	103 b	24 a	81.10 ab	18.90 c
N_4	99.62 a	238 c	216 c	22.14 b	84 c	23 b	78.50 b	21.50 b
N_5	100.78 a	324 a	294 a	27.02 a	115 a	22 b	83.33 a	16.67 d
N_6	103.45 a	322 a	281 ab	26.95 a	110 ab	24 a	82.09 a	17.91 d
N_7	82.65 b	225 c	211 c	21.56 b	71 c	27 a	72.45 c	27.55 a
$LSD_{(0.05)}$	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 (%)
2022 Dry Season				
N_1	6.39 a	6.78 a	13.17 a	48.52 a
N_2	5.96 b	6.45 a	12.41 a	48.03 a
N_3	5.13 c	5.82 ab	10.95 b	46.85 a
N_4	5.05 c	5.48 b	10.53 b	47.96 a
N_5	6.68 a	7.04 a	13.72 a	48.69 a
N_6	6.26 ab	6.87 a	13.13 a	47.68 a
N_7	3.51 d	4.67 c	8.18 c	42.91 b
$LSD_{(0.05)}$	0.61	0.62	0.71	2.89
F-test	0.01	0.01	0.01	0.05
2023 Dry Season				
N_1	6.49 a	6.91 a	13.40 a	48.43 a
N_2	5.89 b	6.78 a	12.67 b	46.49 a
N_3	5.21 c	5.96 b	11.17 c	46.64 a
N_4	4.96 c	5.53 b	10.49 c	47.28 a
N_5	6.75 a	7.07 a	13.82 a	48.84 a
N_6	6.31 ab	6.89 a	13.20 a	47.80 a
N_7	3.49 d	4.73 c	8.22 d	42.46 b
$LSD_{(0.05)}$	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^{-1})	S content in grain (%)
2022 Dry Season					
N_1	1.43 a	0.196 a	0.151 a	96.49 a	0.126 a
N_2	1.51 a	0.191 a	0.156 a	92.98 a	0.129 a
N_3	1.20 b	0.195 a	0.132 b	67.72 b	0.128 a
N_4	1.13 b	0.191 a	0.121 bc	61.11 b	0.121 a
N_5	1.43 a	0.202 a	0.148 a	98.86 a	0.126 a
N_6	1.54 a	0.199 a	0.143 ab	89.52 a	0.128 a
N_7	0.53 c	0.153 b	0.115 c	40.37 c	0.082 b
$LSD_{(0.05)}$	1.59	0.03	0.01	7.35	0.07
F-test	0.01	0.01	0.01	0.01	0.01
2023 Dry Season					
N_1	1.42 a	0.199 a	0.147 a	95.40 a	0.123 a
N_2	1.42 a	0.193 a	0.159 a	93.65 a	0.127 a
N_3	1.21 b	0.194 a	0.135 b	70.34 b	0.126 a
N_4	1.24 b	0.196 a	0.117 bc	58.03 c	0.125 a
N_5	1.42 a	0.205 a	0.146 a	98.55 a	0.129 a
N_6	1.42 a	0.197 a	0.141 ab	88.97 a	0.124 a
N_7	0.61 c	0.151 b	0.109 c	38.04 d	0.087 b
$LSD_{(0.05)}$	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 (PFP), 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	PFP_N	AE_N	RE_N	PE_N	IE_N	NHI
	(kg kg^{-1})	(kg kg^{-1})	(%)	(kg kg^{-1})	(kg kg^{-1})	(kg kg^{-1})
2022 Dry Season						
N_1	85 b	38.40 a	1.24 a	37.60 b	66 c	0.50 a
N_2	60 c	24.50 c	0.89 c	33.83 c	64 c	0.58 a
N_3	103 a	32.40 b	1.28 a	42.05 a	76 ab	0.34 b
N_4	0 d	0.00 d	0.00 d	0.00 d	83 a	0.09 c
N_5	80 b	37.74 a	1.13 b	40.52 b	68 c	0.48 a
N_6	67 c	29.57 b	0.92 c	44.76 a	70 b	0.55 a
N_7	0 d	0.00 d	0.00 d	0.00 d	87 a	0.15 c
$LSD_{(0.05)}$	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
2023 Dry Season						
N_1	87 b	40.00 a	1.22 b	38.01 b	68 bc	0.51 a
N_2	59 d	24.00 d	0.09 d	36.86 b	63 c	0.58 a
N_3	104 a	34.40 b	1.33 a	38.08 b	74 b	0.33 c
N_4	0 e	0.00 e	0.00 e	0.00 c	85 a	0.09 d
N_5	80 b	38.81 a	1.13 c	38.67 b	68 bc	0.48 b
N_6	68 c	30.32 c	0.91 d	42.41 a	71 b	0.55 a
N_7	0 e	0.00 e	0.00 e	0.00 c	92 a	0.16 d
$LSD_{(0.05)}$	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.

Acknowledgement: The authors are highly grateful to the Department of Soil Science, Sher-E-Bangla Agricultural University, Dhaka for providing all the necessary facilities and support and Bangladesh Rice Research Institute, Gazipur for seed, scientific information and co-supervisor.

REFERENCES

1. Gondwal, P., Rana, M.K., Dhankar, Amit, Sahil and Mohan, J. (2024). Role of nano-urea in optimizing nitrogen use efficiency, yield and quality of rice: A review. *Intl. J. Res. Agron*., SP-7(10): 182-187.
2. Jahan, S., Sarkar, M.A.R. and Paul, S.K. (2017). Variations of growth parameters in transplanted Aman rice (cv. BRRI dhan39) in response to plant spacing and fertilizer management. *Archives Agril. Env. Sci*., 2(1) 1-5.
3. Das, P.R., Zaber Hossain, M.Z. and Akter, F. (2024). Rice (*Oryza sativa* L.) yield and potassium use efficiency as affected by potassium fertilizer sources. *South Asian J. Agril. Sci*., 4(1): 22-27.
4. World Food and Agriculture – Statistical Yearbook (2023). FAO. https://doi.org/10.4060/cc8166en.
5. FAO (Food and Agriculture Organization) (2022). FAOSTAT Production Statistics. Food and Agriculture Organization. Rome, Italy.
6. Mahbub, M.M., Bhuiyan, M.K.A. and Mir Kabir, M.M. (2017). Performance of Metsulfuron Methyl 10% + Chlorimuron Ethyl 2% WP against annual weed inhibition in transplanted rice. *Haya: Saudi J. Life Sci*., 2(8) 298-305.
7. Zhang, T., He. X., Chen, B., He, L. and Tang, X. (2021). Effects of Different Potassium (K) Fertilizer Rates on Yield Formation and Lodging of Rice. *Phyton*, 90(3): 815-826.
8. Habib, F., Javid, S., Saleem, I., Ehsan, S. and Ahmad, Z.A. (2014). Potassium dynamics in soil under long term regimes of organic and inorganic fertilizer application. *Soil and Env.*, 33(2): 110-115.
9. Dhillon, J.S., Eickhoff, E.M., Mullen, R.W. and Raun, W.R. (2019). World potassium use efficiency in cereal crops. *Agron. J*., 111: 889-896.
10. Sattar, A., Naveed, M., Ali, M., Zahir, Z.A., Nadeem, S.M. Yaseen, M. (2019). Perspectives of potassium solubilizing microbes in sustainable food production system: *A review. Applied Soil Ecology*, 133: 146-159.
11. Hartati, S., Suryono, and Purnomo, D. (2018). Effectiveness and efficiency of potassium fertilizer application to increase the production and quality of rice in Entisols. *IOP Conference Series: Earth and Environ. Sci*., 142: 012031.
12. Popp, M.P., Slaton, N.A., Norsworthy, J.S. and Dixon, B. (2020). Rice yield response to potassium: An economic analysis. Agronomy J., 113: 287-297.
13. Ranjha, A.M., Waheed, T., Mehdi, S.M. and Rehman, S.S. (2001). Effect of potassium sources on rice yield. *Intl. J. Agric. & Biol*., 3(1):69-71.
14. Saha, P.K., Miah, M.A.M., Hossain, A.T.M.S., Ahman, F.R. and Saleque, M.A. (2009). Contribution of rice straw to potassium supply in rice fallow-rice cropping pattern. *Bangladesh J. Agril. Res*., 34(4): 633-643.
15. Sharma, P., Abrol, V. and Kumar, R. (2013). Effect of water regimes and nitrogen levels on rice crop performance and nitrogen uptake. *Indian J. Soil Conserv*., 40(2): 122-128.
16. Islam, S.M.M., Gaihre, Y.K., Shah, A.L., Singh, U., Sarkar, M.I.U., Satter, M.A., Sanabria, J. and Biswas, J.C. (2016). Rice yields and nitrogen use efficiency with different fertilizers and water management under intensive lowland rice cropping systems in Bangladesh. *Nutr. Cycl. Agroecosyst*, 106: 143-156.
17. Liu, H., Liang, W., Wang, G., Connor, D.J. and Rimmington, G.M. (2009). A simulation model assisted study on water and nitrogen dynamics and their effects on crop performance in the wheat-maize system: (II) model calibration, evaluation and simulated experimentation. *Frontiers of Agric. in China*, 3(2): 109-121.
18. Karmakar, B., Haefele, S.M., Henry, A., Kabir, M.H., Islam, A. and Biswas, J.C. (2021). In Quest of Nitrogen Use-Efficient Rice Genotypes for Drought-Prone Rainfed Ecosystems. *Frontiers in Agron*., 2: 607792.
19. Dobermann, A. and Fairhurst, T. (2000). Rice nutrient disorders and nutrient management. International Rice Research Institute, Manila, Philippines. Hand book Series. pp. 41-47, 155-157.Dobermann, 2005;
20. Singh, H., Verma, A., Ansari, M.W. and Shukla, A. (2014). Physiological response of rice (*Oryza sativa* L.) genotypes to elevated nitrogen applied under field conditions. *Plant Signaling and Behavior*, 9: 1-7.
21. Gomez, K.A. and Gomez, A.A. (1984). Statistically procedures for agricultural research. 2^{nd} edition. An International Rice Research Institute Book. *A wiley-International science Publication* New York 28: 442-443.
22. Fageria, N.K., de Morais, O.P. and dos Santos, A.B. (2010). Nitrogen use efficiency in upland rice genotypes. *J. Plant Nutri*., 33: 1696-1711.
23. Swain, J., Panda, R.K., Nayak, R.K. and Satapath, M. (2024). Nutrient use efficiency of rice genotypes under iron-toxic lowland soil influenced by high potassic fertilizer and foliar application of kinetin. *Plant Sci. Today*, 11(3): 460-468.
24. Wihardjaka, A., Harsanti, E.S. and Ardiwinata, A.N. (2021). Effect of fertilizer management on potassium dynamics and yield of rainfed lowland rice in Indonesia. *Chilean J. Agril. Res*., 82(1): 33-43.
25. Kumar, R., Sandeep, K., Anil, K., Harnam, S. and Sanjeev, K. (2013). Effect of top dressing nitrogen and potassium on yield and yield component of rice (*Oryza sativa* L). *Agriways*, 1(2): 90-94.