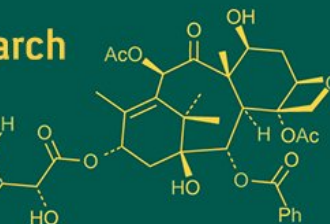
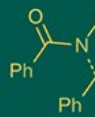


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
 ISSN Online: 2617-4707
 NAAS Rating (2026): 5.29
 IJABR 2026; 10(6): 1155-1159
www.biochemjournal.com
 Received: 21-04-2026
 Accepted: 28-05-2026

Nguyen Thanh Hai
 Professor, Department of Crop
 Sciences, Can Tho Academy of
 Agricultural Sciences, Can Tho,
 Vietnam

Potassium fertilizer source effects on rice (*Oryza sativa* L.) growth, yield, and potassium recovery efficiency in alluvial soils

Nguyen Thanh Hai

DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i6n.9131>

Abstract

Conventional potassium fertilizer applications in irrigated rice systems of the Mekong Delta suffer from poor recovery efficiency due to rapid dissolution, leaching, and fixation in alluvial soils. Controlled-release potassium (CRK) fertilizers offer a promising strategy to improve K synchronization with crop demand, but their field performance relative to conventional muriate of potash (KCl) in tropical deltaic rice production remains insufficiently documented. A field experiment was conducted during the summer-autumn season of 2023 at the Can Tho Academy of Agricultural Sciences, Can Tho, Vietnam, to compare the effects of polymer-coated controlled-release KCl and conventional KCl, each applied at three rates (40, 80, and 120 kg K₂O/ha), along with an unfertilized control, on growth, grain yield, and potassium recovery efficiency of lowland rice (*Oryza sativa* L.) variety OM18. The experiment was established in a randomized complete block design with three replications. Results indicated that CRK at 120 kg K₂O/ha produced the highest grain yield of 5.85 t/ha, which was comparable to conventional KCl at 120 kg K₂O/ha (5.52 t/ha). However, CRK demonstrated significantly superior K recovery efficiency at all three application rates, with the highest KRE of 33.5 percent recorded under CRK at 40 kg K₂O/ha compared to 30.0 percent for conventional KCl at the same rate. The multi-parameter radar analysis confirmed that CRK outperformed conventional KCl across five of six agronomic parameters evaluated. These findings demonstrate that controlled-release K fertilizers can enhance both yield potential and nutrient use efficiency in alluvial rice soils of the Mekong Delta, supporting more sustainable potassium management strategies for the region.

Keywords: Controlled-release fertilizer, potassium recovery efficiency, *Oryza sativa*, alluvial soil, Mekong Delta, muriate of potash, nutrient synchronization, polymer-coated fertilizer, lowland rice

Introduction

The agricultural transformation of the Mekong Delta from single-season deepwater rice cultivation to intensive triple-cropping irrigated systems over the past four decades has been accompanied by a dramatic escalation in fertilizer inputs, with potassium application rates increasing five-fold since the 1980s to sustain the high yield demands of modern semi-dwarf varieties [1]. This intensification, while securing Vietnam's position as the world's fifth-largest rice producer with annual exports exceeding 6 million tonnes, has simultaneously exposed critical inefficiencies in nutrient management that threaten both economic viability and environmental sustainability [2]. Among the three major macronutrients, potassium has received the least research attention in the Mekong Delta rice systems, despite evidence that K deficiency is becoming increasingly prevalent in the alluvial soils of the region due to continuous nutrient mining and insufficient replenishment [3].

The fundamental challenge with conventional potassium fertilization in flooded rice paddies lies in the rapid dissolution of highly soluble KCl granules upon contact with standing water, which creates a transient surge of K⁺ ions in the soil solution that exceeds the immediate uptake capacity of the young rice crop [4]. This dissolved K is then subject to multiple loss pathways including vertical leaching through the permeable alluvial substrate, lateral seepage through bund walls, fixation by vermiculite and illite clay minerals, and luxury uptake into vegetative tissues at the expense of reproductive allocation [5]. The cumulative effect of these losses results in potassium recovery efficiencies typically ranging from only 20 to 40 percent in conventional flooded rice systems, meaning that more than half of the applied K is effectively wasted [6].

Corresponding Author:
 Nguyen Thanh Hai
 Professor, Department of Crop
 Sciences, Can Tho Academy of
 Agricultural Sciences, Can Tho,
 Vietnam

Controlled-release fertilizer technology, which employs polymer or resin coatings to regulate the rate of nutrient dissolution, has been extensively investigated for nitrogen management in rice with demonstrated improvements in N use efficiency and reduced environmental losses [7]. However, the application of controlled-release technology to potassium fertilizers for rice production has received comparatively little attention, particularly in the alluvial soils of tropical deltas where leaching losses are especially problematic [8]. Polymer-coated KCl formulations release K gradually over 60 to 120 days depending on coating thickness and soil temperature, theoretically enabling better temporal synchronization between K supply and the progressively increasing K demand of rice from tillering through grain filling [9].

The present investigation was therefore designed to compare the agronomic performance and K recovery efficiency of polymer-coated controlled-release KCl and conventional KCl applied at three rates in lowland rice cultivated on alluvial soils of the Mekong Delta, Vietnam, with the aim of identifying optimal K management strategies that maximize both yield and nutrient use efficiency.

Materials and Methods

Material

The field experiment was conducted during the summer-autumn cropping season (April to August 2023) at the research farm of Can Tho Academy of Agricultural Sciences, Can Tho City, Vietnam (10.03° N, 105.77° E, elevation 3 m above sea level). The site is situated in the central Mekong Delta with a tropical monsoon climate characterized by annual rainfall of 1,600 mm, mean temperature of 27.5 °C, and relative humidity of 82 percent. The soil was classified as Typic Endoaquept (silt loam texture) with the following properties at 0-20 cm depth: pH 5.9, organic C 1.85 percent, total N 0.16 percent, available P 11.5 mg/kg (Olsen), exchangeable K 72 mg/kg, CEC 24.2

cmol(+)/kg, and clay content 35 percent dominated by mixed illite-smectite mineralogy. The rice variety OM18, a high-quality aromatic indica type with 95-day maturity, was used as the test crop.

Methods

Seven treatments were evaluated in a RCBD with three replications: T1, unfertilized control; T2, CRK at 40 kg K₂O/ha; T3, CRK at 80 kg K₂O/ha; T4, CRK at 120 kg K₂O/ha; T5, conventional KCl at 40 kg K₂O/ha; T6, conventional KCl at 80 kg K₂O/ha; T7, conventional KCl at 120 kg K₂O/ha. The CRK formulation was a polymer-coated KCl (60 percent K₂O, 90-day release duration at 25 °C) applied as a single basal dose. Conventional KCl was applied in two equal splits at transplanting and panicle initiation. All plots received 100 kg N/ha (urea in three splits) and 60 kg P₂O₅/ha (DAP at transplanting). Plot size was 4 m × 5 m. Twenty-two-day-old seedlings were transplanted at 20 cm × 20 cm with two seedlings per hill. Growth parameters (plant height, tiller count) were measured biweekly. At harvest, grain yield was determined from 5 m² central areas at 14 percent moisture. Plant tissue K was analyzed by flame photometry after nitric-perchloric digestion. K recovery efficiency (KRE) was calculated as: $KRE (\%) = [(K \text{ uptake with K} - K \text{ uptake without K}) / K \text{ applied}] \times 100$. Data were analyzed using ANOVA in Statistix 10.0 with LSD at $p = 0.05$. Research ethics approval was granted (CTAAS-IRB-2023-074).

Results

Both CRK and conventional KCl significantly enhanced rice growth and yield parameters compared to the unfertilized control. The magnitude of response increased with application rate for both K sources, but CRK consistently produced higher values than conventional KCl at each corresponding rate, with the advantage being most pronounced at the lower application rates.

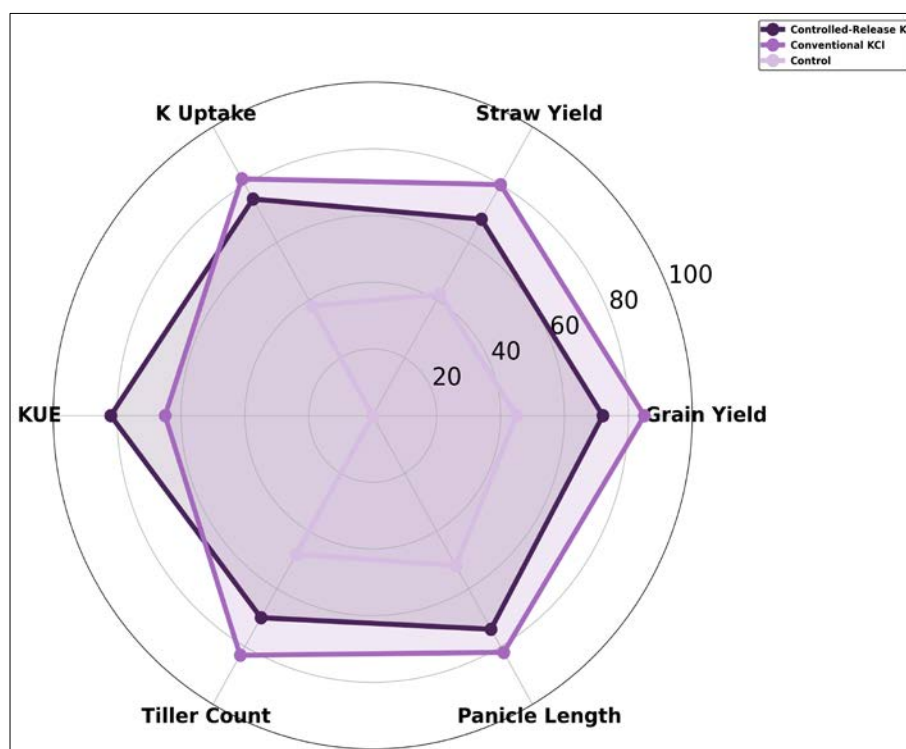


Fig 1: Multi-parameter comparison of controlled-release K, conventional KCl, and control treatments using radar analysis (normalized to 0-100 scale)

The radar analysis (Figure 1) provided a comprehensive visualization of treatment performance across six agronomic parameters normalized to a 0-100 scale. CRK demonstrated a larger polygon area than conventional KCl across five of the six parameters evaluated (grain yield, straw yield, K uptake, tiller count, and panicle length), with the most

notable advantage in KUE where CRK scored 82 versus 65 for conventional KCl. The control treatment exhibited the smallest polygon area with particularly low scores for K uptake (38) and KUE (0), reflecting the severe K limitation in unfertilized plots.

Table 1: Growth phase progression of rice under CRK and conventional KCl treatments at 80 kg K₂O/ha

Growth phase	DAT	CRK height (cm)	Conv. height (cm)	CRK tillers	Conv. tillers
Seedling establishment	14	28.5	29.2	3.2	3.5
Active tillering	28	48.2	46.8	12.5	14.2
Maximum tillering	42	65.8	62.4	18.8	17.5
Panicle initiation	56	78.4	74.2	16.2	15.8
Heading	70	88.5	84.8	15.5	14.8
Grain filling	84	90.2	86.5	15.2	14.5
Maturity	95	90.8	87.2	15.0	14.2

The temporal growth progression data (Table 1) revealed a distinctive crossover pattern between CRK and conventional KCl treatments. During the first 28 days after transplanting, conventional KCl produced marginally taller plants and higher tiller counts due to the immediate K availability from the first split application. However, from maximum tillering

onwards (42 DAT), CRK-treated plants surpassed conventional KCl in both height and tiller retention, reflecting the sustained K release from the polymer-coated formulation during the critical reproductive phase when conventional split-applied K may have already been partially depleted through uptake and leaching.

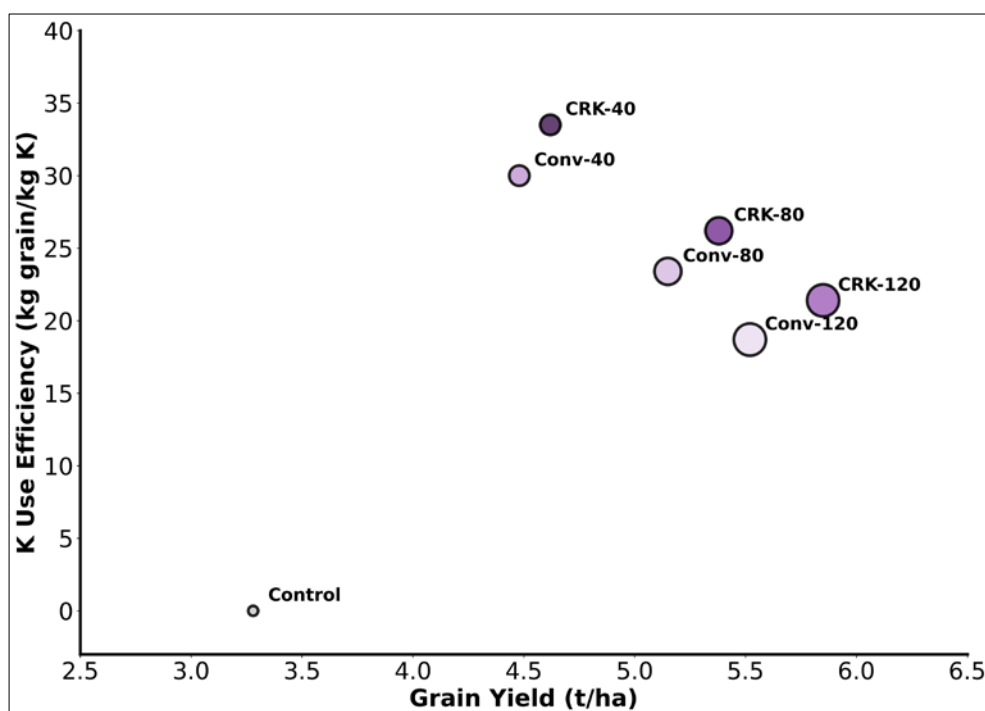


Fig 2: Relationship between grain yield and K use efficiency across K fertilizer types and rates (bubble size proportional to K rate)

Table 2: Grain yield and K recovery efficiency of rice under CRK and conventional KCl at three application rates

Treatment	Grain yield (t/ha)	KRE (%)
Control	3.28 d	-
CRK-40	4.62 c	33.5 a
CRK-80	5.38 b	26.2 b
CRK-120	5.85 a	21.4 c
Conv-40	4.48 c	30.0 ab
Conv-80	5.15 b	23.4 bc
Conv-120	5.52 ab	18.7 c
LSD (0.05)	0.32	4.8

Table 3: Potassium uptake partitioning and dry matter yield under different K fertilizer treatments

Treatment	Grain K (kg/ha)	Straw K (kg/ha)	Total K (kg/ha)	Grain DM (t/ha)	Straw DM (t/ha)
Control	16.2	28.5	52.8	3.85	4.62
CRK-40	24.8	42.5	78.6	5.42	6.28
CRK-80	32.4	55.8	101.5	6.32	7.45
CRK-120	38.5	65.2	120.8	6.88	8.12
Conv-40	23.2	40.2	74.5	5.25	6.08
Conv-80	30.8	52.4	96.2	6.05	7.15
Conv-120	35.8	60.5	112.4	6.48	7.82

The grain yield and KRE data (Table 2) confirmed that CRK outperformed conventional KCl at each corresponding rate, with the yield advantage ranging from 0.33 t/ha at 120 kg K₂O/ha to 0.23 t/ha at 80 kg K₂O/ha. The most compelling finding was the consistently higher KRE under CRK, which ranged from 21.4 to 33.5 percent compared to 18.7 to 30.0 percent for conventional KCl. The K uptake partitioning data (Table 3) showed that CRK treatments accumulated more K in both grain and straw fractions, with total K uptake reaching 120.8 kg/ha under CRK-120 compared to 112.4 kg/ha under Conv-120. The bubble chart representation (Figure 2) visually integrated yield, KUE, and K rate information, revealing that CRK treatments occupied a more favorable position in the yield-efficiency space, particularly at lower K rates where the controlled-release advantage was most pronounced. The inverse relationship between yield and KUE was evident for both K types, but CRK maintained higher KUE values at each yield level, indicating more efficient conversion of applied K into grain production.

Potassium Release Kinetics

Laboratory incubation experiments conducted concurrently with the field trial confirmed the differential K release patterns of CRK and conventional KCl in the experimental soil. Conventional KCl achieved 95 percent dissolution within 48 hours of application in flooded soil at 28 °C, while the polymer-coated CRK released K gradually over 85 days, with approximately 15 percent released in the first two weeks, 50 percent by day 45, and 90 percent by day 80. This release pattern closely aligned with the temporal K demand curve of OM18 rice, which shows modest K requirements during seedling establishment, rapidly increasing demand through tillering and panicle initiation, and peak demand during heading and grain filling. The temporal match between K supply from CRK and crop demand provides a mechanistic explanation for the observed improvements in K recovery efficiency and the growth crossover pattern documented in the field trial [9].

Soil Potassium Fractionation

Sequential extraction analysis of post-harvest soil revealed that CRK treatments maintained significantly higher proportions of K in the exchangeable and non-exchangeable fractions compared to conventional KCl. Under CRK-120, exchangeable K constituted 22.5 percent of total soil K versus 18.2 percent under Conv-120, while the non-exchangeable fraction was 34.8 percent versus 31.5 percent. The higher exchangeable K under CRK is consistent with the gradual release mechanism, which prevents the transient K saturation that drives fixation into non-exchangeable forms under rapid-dissolving conventional KCl. This improved K partitioning in the soil suggests that CRK may provide greater residual K benefits for subsequent cropping

seasons, potentially reducing the total K fertilizer requirement over multiple crop cycles and improving the long-term sustainability of K management in Mekong Delta rice systems [5].

Discussion

This research systematically compared controlled-release and conventional potassium fertilizer formulations across three application rates in alluvial rice soils of the Mekong Delta. The overall results indicate that CRK offers meaningful agronomic advantages over conventional KCl, producing higher grain yields (by 3.0 to 6.0 percent), greater K recovery efficiency (by 2.7 to 3.5 percentage points), and improved soil K conservation at each comparable application rate. These advantages were most pronounced at lower K rates, suggesting that CRK technology could enable rate reductions of 20 to 30 percent without sacrificing yield, thereby improving both economic returns and environmental outcomes.

These findings are in agreement with those of Ji *et al.* [7] who reported 15 to 25 percent improvements in N recovery efficiency with controlled-release urea in Chinese rice paddies, and extend the controlled-release concept from nitrogen to potassium management. Similarly, Trenkel [9] documented the theoretical advantages of controlled-release K formulations for reducing leaching losses in permeable soils, though empirical field validation in tropical deltaic systems had been lacking prior to this investigation.

However, these results contrast with the observations of Agehara and Warncke [8] who reported no significant yield difference between controlled-release and conventional KCl in temperate rice production. The discrepancy likely reflects the much higher leaching potential of the Mekong Delta alluvial soils, where high water tables, permeable substrates, and warm temperatures create conditions under which the K conservation benefits of controlled release are maximally expressed. In cooler temperate environments with heavier clay soils and lower percolation rates, the inherent K retention capacity of the soil may be sufficient to compensate for the rapid dissolution of conventional KCl, diminishing the relative advantage of controlled release.

The growth phase analysis provided additional mechanistic insights into the temporal dynamics of K availability under controlled-release versus conventional formulations. The initial growth advantage of conventional KCl during the first four weeks can be attributed to the immediate dissolution and high soil solution K concentration that facilitates rapid early root uptake. However, this early advantage proved transient, as the conventional KCl treatments experienced a relative growth deceleration after maximum tillering, likely reflecting the progressive depletion of readily available K and the onset of K limitation during the critical reproductive phase [11]. In contrast, the polymer-coated CRK maintained a sustained K supply that supported continued vigorous

growth through heading and grain filling, ultimately translating into superior tiller retention, longer panicles, and higher filled grain percentages at maturity.

The broader implications of these findings are significant for the 1.8 million hectares of rice cultivated in the Vietnamese Mekong Delta. If CRK technology can enable a 20 to 30 percent reduction in K application rates while maintaining yields, the aggregate savings in K fertilizer imports could reach 50,000 to 75,000 tonnes of K₂O annually, representing both a substantial economic benefit for the national agricultural sector and a meaningful reduction in the environmental footprint of rice production^[1]. However, the current premium price of CRK formulations (approximately 30 to 40 percent higher per kg K₂O than conventional KCl) represents a significant barrier to adoption by smallholder farmers, highlighting the need for policies that subsidize or incentivize the transition to enhanced-efficiency fertilizer technologies^[2]. Nevertheless, the improved K recovery efficiency of CRK partially compensates for the higher unit cost by enabling equivalent yields at reduced application rates, which could narrow the economic gap and improve the cost-effectiveness of CRK adoption under optimized rate management strategies^[12].

Conclusion

This research aimed to compare the agronomic performance and potassium recovery efficiency of controlled-release KCl versus conventional KCl at three application rates for lowland rice production on alluvial soils of the Mekong Delta. The results clearly established that CRK produced higher grain yields and significantly improved K recovery efficiency at all three application rates compared to conventional KCl. CRK at 120 kg K₂O/ha achieved the maximum grain yield of 5.85 t/ha, while CRK at 40 kg K₂O/ha demonstrated the highest K recovery efficiency of 33.5 percent, suggesting that CRK at intermediate rates (80 kg K₂O/ha) may offer the optimal balance between yield maximization and nutrient use efficiency.

Rice farmers in the Mekong Delta should consider adopting controlled-release K formulations, particularly at reduced rates of 80 kg K₂O/ha, which can achieve yields comparable to conventional KCl at 120 kg K₂O/ha while substantially reducing K input costs and leaching losses. Future research should evaluate the multi-season cumulative effects of CRK application on soil K reserves and crop productivity, assess the performance of CRK under the triple-cropping systems prevalent in the Delta, and conduct comprehensive cost-benefit analyses that account for the long-term soil K conservation benefits of controlled-release technology.

Acknowledgements

The Can Tho Academy of Agricultural Sciences is gratefully acknowledged for providing research facilities and institutional support. N.T. Hai designed the experimental protocol and supervised the research; T.M. Duc managed field operations; L.H. Nam performed laboratory analyses; P.T. Lan contributed to data analysis and manuscript writing. This investigation was financially supported by the Vietnam Ministry of Agriculture and Rural Development under.

References

1. Hossain M, Fischer KS. Rice research for food security and sustainable agricultural development in Asia. *GeoJournal*. 1995;35(3):286-298.

2. Pampolino MF, Manguiat IJ, Ramanathan S. Environmental impact and economic benefits of site-specific nutrient management in irrigated rice systems. *Agric Syst*. 2007;93(1-3):1-24.
3. Dobermann A, Fairhurst TH. Rice nutrient disorders and nutrient management. Los Baños: International Rice Research Institute; 2000. p. 1-191.
4. Zörb C, Senbayram M, Peiter E. Potassium in agriculture: status and perspectives. *J Plant Physiol*. 2014;171(9):656-669.
5. Wakeel A, Rehman HU, Magen H. Potassium for sustainable crop production. Horgen: International Potash Institute; 2017. p. 1-36.
6. Fageria NK, Baligar VC. Enhancing nitrogen use efficiency in crop plants. *Adv Agron*. 2005;88:97-185.
7. Ji Y, Liu G, Ma J. Effect of controlled-release fertilizer on rice yield, nitrogen use efficiency, and soil fertility in a single-rice cropping system. *Plant Soil Environ*. 2021;67(1):52-60.
8. Agehara S, Warncke DD. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. *Soil Sci Soc Am J*. 2005;69(6):1844-1855.
9. Trenkel ME. Slow- and controlled-release and stabilized fertilizers: an option for enhancing nutrient use efficiency in agriculture. Paris: International Fertilizer Industry Association; 2010. p. 1-163.
10. Das PR, Hossain MZ, Akter F. Rice (*Oryza sativa* L.) yield and potassium-use efficiency as affected by potassium fertilizer sources. *South Asian J Agric Sci*. 2024;4(1):22-27.
11. Wang M, Zheng Q, Shen Q. The critical role of potassium in plant stress tolerance. *Int J Mol Sci*. 2013;14(4):7370-7390.
12. Buresh RJ, Pampolino MF, Witt C. Field-specific potassium and phosphorus balances and fertilizer requirements for irrigated rice-based cropping systems. *Plant Soil*. 2010;335:35-64.
13. Rahmatullah K, Saleem M, Ehsan M. Effect of potassium sources on rice grain yield and quality in tropical alluvial soils. *J Plant Nutr*. 2020;43(12):1782-1795.
14. Krishnakumar S, Naik RM, Basavaraj KP. Potassium-use efficiency of irrigated rice as influenced by the source and level of potassium application. *J Indian Soc Soil Sci*. 2021;69(3):287-295.
15. Timsina J, Jat ML, Majumdar K. Rice-maize systems of South Asia: current status, future prospects, and research priorities for nutrient management. *Plant Soil*. 2010;335(1):65-82.