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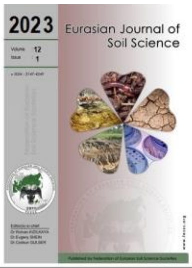

Yield response of rice (*Oryza sativa* L.) to elevated potassium applied under the irrigated ecosystem of Bangladesh

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Abstract

A field experiment was conducted at Bangladesh Agricultural University farm, Mymensingh, Bangladesh, during the Boro season, 2017 with six different K fertilizer rates: 0, 10, 20, 30, 40 and 50 kg ha^{-1} to determine the optimum rate of potassium (K) fertilization for the improved yield of a specific rice variety in the irrigated ecosystem under floodplain area. Compared with no K fertilizer, adding K increased the rice grain and straw yields significantly, with all other yield contributing components, except 1000-grain weight. The highest yield of grain (7.07 ton ha^{-1}) and straw (8.48 ton ha^{-1}) were recorded in recommended fertilizer dose (RFD) of NPS + 50kg K treatment, which were statistically identical with RFD of NPS + 40 kg K. Rice grain and straw yields due to the different treatments increased by 18.65% to 53.74% and 18.67% to 53.78%, respectively over control. K content and uptake through grain and straw were significantly influenced by applying different levels of K. These results specified that the use of 40 kg K ha^{-1} had better performance on the grain and straw yields. Therefore, we conclude that the application of 40 kg K ha^{-1} along with the RFD of NPS for BRRI dhan29 cultivation is the best option for higher yield in Old Brahmaputra Floodplain soil.

Keywords: Boro rice, floodplain, irrigated ecosystem, potassium, yield.

Introduction

Rice (*Oryza sativa* L.) is the principal grain crop for more than half of the world's population (IRRI, 2015). This population is rapidly approaching seven billion, and to meet their demand, global rice production needs to expand by 116 million tons by 2035 (Yamano et al., 2016). Asia has the largest share in rice production as the top rice consuming countries like China, India and Bangladesh are included in this region (Shahbandeh, 2021). Like many other countries, 'food security' in Bangladesh entirely depends on 'rice security'; hence, rice is the backbone of Bangladesh's agriculture (Brolley, 2015). According to BBS (2020), rice alone contributes around 4.5% of GDP.

For increasing rice yield, many techniques and approaches have been examined, such as fertilizer application (Hou et al., 2019), high yielding varieties (Yuan, 2017), irrigation management (Norton et al., 2017), weed control (Chauhan and Opeña, 2013) and frequent planting (Peng et al., 2015). By considering all of these above, soil fertilization is an affirmed strategy to enhance rice production where nitrogen (N), phosphorus (P) and potassium (K) are the most frequently applied nutrients. Compared to N and P, the K fertilizer is usually ignored by farmers as the grain yield response to K is lower than N and P (Li et al., 2014; Hou et al., 2019). However, K is essential for maintaining several physiological and metabolic activities of plants. It is crucial for

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controlling intracellular osmotic regulation, photosynthesis, and membrane protein transport as an enzymatic activator. Moreover, this encompasses a vital position in the transportation of carbohydrates in rice plants and stress resistance (Wang and Wu, 2013; Nieves-Cordones et al., 2019).

BRRI (Bangladesh Rice Research Institute) indicated that rice crops could remove 19.13–22.31 kg K to produce 1.0 tons of grain (Choudhury et al., 2013). However, this requirement can vary according to the variation of yield potential. For instance, rice crops can utilize about 103 kg K for a yield level of 7.0 ton ha^{-1} (FRG, 2012). The variations in K requirement with grain yield levels and cultivars emphasize K requirement's importance in calculating K balance and optimal K fertilizer doses for rice production practice. Furthermore, soil texture can also play a decisive role in selecting the proper fertilizer application rate. The positive response of rice to K was found up to 80 kg ha^{-1} in clay loam grey terrace soils of Bangladesh though there were seasonal and varietal differences in this regard (Naher et al., 2011). The general recommended K for haor areas, which are considered typical wetland ecosystems in Bangladesh, is about 35 kg ha^{-1} to cultivate rice with a yield potential of 7.5 ± 0.75 ton ha^{-1} (FRG, 2012). Low K dose cannot replenish soil K levels quickly to meet the maximum demand for rice crops. For this reason, rice plants can suffer from K deficiency, become more susceptible to biotic and abiotic stresses, and increase disease incidence (Zhang et al., 2019). Besides, several studies described the negative K balances in rice systems (Mohanty and Mandal, 1989; Miah et al., 2008). This negative balance and K mining from the soil are now generating an agitating situation in Bangladesh which varied between −100 and −225 kg ha^{-1} per year (Rijmpa and Islam, 2002). Additionally, researchers reported that the present K fertilizer dose is not enough to support a favourable K fertility status in the soils of Bangladesh (Islam and Muttaleb, 2016).

Therefore, to fight against these problems, there is no alternative other than the judicial application of K fertilizer for specific rice varieties. Quantifying the amount of K taken up from soil solution and soil solid portion may help take necessary measures to reduce the K mining from the soil. In this article, a field experiment was undertaken to determine the optimum rate of K on maximizing yield and yield contributing characters for a specific rice variety, BRRI dhan29.

Material and Methods

Site description

The experiment was conducted in 2017 at the Soil Science Field Laboratory of Bangladesh Agricultural University, Mymensingh, Bangladesh (Figure 1), during the Boro season (winter season). Mymensingh district falls under the Agro-Ecological Zone-9 of the Old Brahmaputra floodplain. This area belongs to the sub-tropical climate and is characterized by high temperatures accomplished by moderately high rainfall during the Kharif season (April to September) and low temperatures in the Rabi season (October to March). The land is moderately well-drained, and the land type is medium high. The famous high yielding Boro rice variety BRRI dhan29 was used as a test crop. It is a high yielding rice variety. The growth duration is around 155 to 160 days (BRRI, 2022). The physio-chemical characteristics of soil at the study site in Mymensingh, Bangladesh, are presented in Table 1.

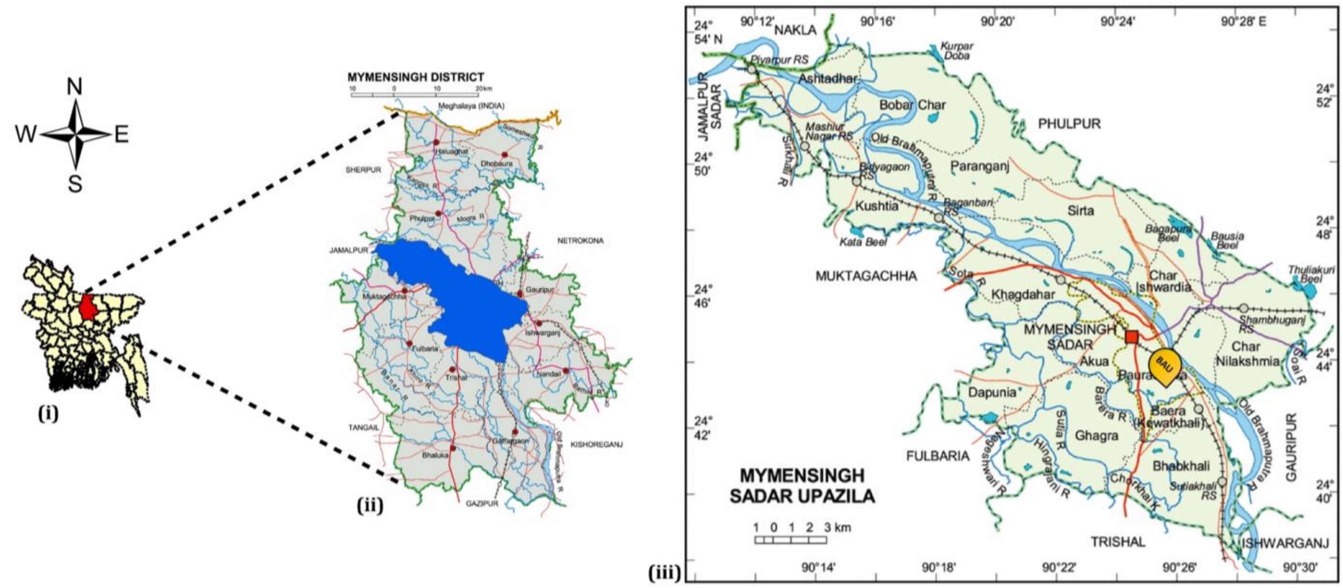

Figure 1. Map of the study site. (i) Location of study site in Bangladesh, (ii) Mymensingh district with study site and (iii) The specific area of our interest (ArcMap version 10.5)

Table 1. Physical and chemical properties of the soil sample

Properties	Methods	Values
Sand (%)		13.28
Silts (%)	Hydrometer method	74.00
Clay (%)		12.72
Textural class		Silt loam
pH	pH meter (glass electrode)	6.88
Organic matter (%)	Walkley and Black method	2.96
Total N (%)	Micro-Kjeldahl distillation method	0.18
Available P (ppm)	Olsen method	12.23
Exchangeable K (meq 100g^{-1} soil)	1 N NH_4OAc method	0.13
Available S (ppm)	0.01 M $Ca(H_2PO_4)_2$ extraction method	11.90
Cation Exchange Capacity, CEC (me 100g^{-1} soil)	Sodium Acetate method	12.70

Experimental design and treatments

Field preparation was started in January 2017. The experiment was placed in a Randomized Complete Block Design (RCBD). The entire experimental area was divided into four blocks with four replications to reduce soil heterogeneity, and each block was sub-divided into seven plots with raised bunds as per treatment. The unit plot size was 4m ×2.5m, and 0.5m bunds separated the plots. Therefore, the Seven treatment combinations were designated as

1. T1=Control (No fertilizer)
2. T2= RFD of NPS +K_0
3. T3=RFD of NPS +K_{10}
4. T4=RFD of NPS+K_{20}
5. T5=RFD of NPS+K_{30}
6. T6=RFD of NPS+K_{40}
7. T7=RFD of NPS+K_{50}

Recommended fertilizer dose (RFD) is N: P: S= 110: 20: 18 kg ha^{-1}

The nutrient source for nitrogen (N) was Urea, phosphorus (P) as Triple Super Phosphate (TSP), potassium (K) as Muriate of Potash (MoP) and sulphur (S) as Gypsum.

Crop management

The total dose of Triple Super Phosphate (TSP) and gypsum was applied during the final land preparation. Urea was applied in three equal splits: (a) one-third 15 days after transplanting, (b) second instalment after 30-35 days of transplanting and (c) the third instalment after 45-50 days after transplanting. Potassium was applied according to different treatments from Muriate of Potash (MoP). Forty days old seedlings were transplanted with a spacing of 20 cm x 20 cm. Three seedlings were transplanted on each hill. All intercultural operations were done to ensure and maintain the crop's expected growth. All the agronomical practices viz. irrigation, fertilizer application and intercultural operations were followed as recommended for rice crop in this specific area.

Data collection from the field

Five hills were randomly selected from each plot at the maturity stage to record the yield contributing characteristics like plant height, number of tillers hill^{-1}, panicle length, number of grains panicle^{-1}, and 1000-grain weight. The selected hills were collected before the crop harvest, and necessary information was documented accordingly. Grain and straw yields were recorded plot-wise at 14% moisture content and expressed as ton ha^{-1} on a fresh weight basis. In addition, grain and straw sub-samples were kept for chemical analysis.

Chemical analysis of grain and straw

The collected grain and straw sample from each plot was dried in an oven at 65^{0}C for about 24 hours, after which the grinding machine ground them. The prepared pieces were then put into paper bags and kept for analysis.

Plant samples of 0.5 g (grain and straw separately) were transferred into the digestion flask. Ten ml of the di-acid mixture (HNO_3 : $HClO_4$ = 2:1) were added into the flask. It was left for some time so that the temperature could slowly rise to 185^{0}C. Heating was stopped when the dense white fume of $HClO_4$ appeared. After cooling, the contents were taken into 50 ml volumetric flasks, and the volume was levelled with distilled water. K was determined from the extract by using a flame photometer. After chemical analysis of straw and grain samples, the nutrient uptake was calculated from the nutrient content and yield of rice crops by the following formula:

$$\text{Nutrient uptake} = \frac{\text{Nutrient content (\%)} \times \text{yield (kg per ha)}}{100}$$

Statistical analysis

Statistical analyses were performed using SPSS V. 25 software. The analysis of variance (ANOVA) for specific characters of rice crops with different nutrient concentrations and nutrient uptake was done following the F-test. Mean comparisons of the treatments were prepared by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ level.

Results and Discussion

Fertilizer application has been inspected broadly by researchers to enhance crop production (Peng et al., 2010; Gu et al., 2017). This study described the necessity of optimum fertilization. Grain and straw yield with other yield contributing attributes are influenced significantly by the increasing K level.

Yield components

The first four yield contributing components (plant height, effective tillers hill^{-1}, panicle length and filled grains panicle^{-1}) were highly affected by the application of K fertilizer except for the fifth one, which was 1000-grain weight. There were significant interaction effects of K on all these parameters without the last one (Table 2).

According to field experiment results, the plant height varied from 74.25cm in the control treatment to 82.03 cm in the RFD of NPS+K_{50} treatment. However, the highest plant height recorded in NPS+K_{50} treatment was statistically similar to NPS+K_{30} and NPS+K_{40} treatments.

The K fertilizer application showed apparent effects for the following three components also. These three components represented the maximum outcome when treated with the RFD of NPS+K_{50} (effective tillers hill^{-1}, panicle length, and filled grains panicle^{-1} were 12.00, 23.62 cm, and 103.5 for this treatment implementation, respectively). Interestingly, these three parameters that exhibited the highest results during the RFD of NPS+K_{50} application was statistically identical to those found in the treatments NPS+K_{40}, NPS+K_{30}, and NPS+K_{20}.

There was an insignificant effect of different K levels on 1000-grain weight of BBRI dhan29. The grain weight varied from 21.65 to 22.8 g (Table 2). The highest 1000-grain weight (22.8 g) was found in treatment T7, and the lowest (21.65 g) value was obtained in treatment T1.

Table 2. Effect of different treatments of K on the yield contributing characters of BRRI dhan29

Treatments	Plant height (cm)	Effective Tillers Hill^{-1}	Panicle Length (cm)	Filled grains panicle^{-1}	1000-grain weight (g)
Control	74.25e	8.00f	20.51e	75.50e	21.65
RFD of NPS+K_0	77.75d	9.00e	21.92d	81.43d	21.97
RFD of NPS+K_{10}	77.93bc	9.50cd	22.73bc	82.68bc	22.02
RFD of NPS+K_{20}	78.03ab	10.00abc	22.88ab	89.87ab	22.12
RFD of NPS+K_{30}	78.43ab	10.75ab	23.05ab	95.12ab	22.30
RFD of NPS+K_{40}	79.25ab	11.75a	23.23a	101.87a	22.72
RFD of NPS+K_{50}	82.03a	12.00a	23.62a	103.50a	22.80
SE (±)	0.86	0.55	0.39	4.04	0.15
CV (%)	2.93	14.36	4.63	11.88	1.86

Figures in a column having common letter(s) do not differ significantly at 5% level of significance. CV and SE denote coefficient of variation and stand error of means, respectively.

Our analysis of yield contributing components indicated that the addition of K fertilizer improved the overall status for all only except the 1000-grain weight. K application at a level higher than the recommended dose consistently raised the plant height. The results also revealed that the RFD of NPS+K_{50} application produced the peak plant height, and this treatment was the best among all other treatments (Table 2). Bahmaniar et al. (2007) found that plant height increased significantly due to K application. The same outcome was also recorded by Mukherjee and Sen (2005) and Biswas et al. (2001) as K encompasses major role in promoting plant stem elongation (Marschner, 1995). Likewise, the effective tillers hill^{-1}, panicle length, and the number of filled grains panicle^{-1} also increased with the increasing rate of K fertilizer. Our findings agree with other researchers who demonstrated that increasing K application positively impacts the improvement of these specific yield contributing parameters (Krishnappa et al., 1990; Mitra et al., 2001; Bahmaniar et al., 2007). Asif et al. (2007) reported that K application as full dose can enhance the flowering, grain number and early physiological maturity in plants. In accordance with Zhang et al. (2019) and Cheema et al. (2012), the use of non-structural carbohydrates in the vegetative part of plants increase when an adequate K supply is confirmed. This may improve the leaf area index and natural buffering capacity of rice for grain filling, which can eventually contribute to the final yield. However, there was no significant effect on the 1000-grain weight of BRRI dhan29 by applying different levels of K fertilizer. Bahmaniar et al. (2007) also reported the identical consequence.

Grain and straw yield

The grain and straw yields of rice are displayed in Table 3. It represents that both parameters were significantly improved by applying K fertilizer. The highest grain yield response of BRRI dhan29 rice variety (7.07 ton ha^{-1}) was obtained with the RFD of NPS+K_{50} treatment which was more than double the control (3.27 ton ha^{-1}). Treatments T6 (RFD of NPS+K_{40}) and T5 (RFD of NPS+K_{30}) with grain yield of 6.79 and 5.70 ton ha^{-1}, respectively, demonstrated statistically similar results with the T7 (RFD of NPS+K_{50}), indicating no different effects among these three treatments. Furthermore, the increase in grain yield over control ranged from 18.65 to 53.74%, where the highest percentage (53.74%) of increased grain yield over the control was recorded in treatment T7, and the lowest rate was observed in treatment T2.

The straw yield of rice also followed the same theme as grain yield. Plots treated with RFD of NPS+K_{50} showed maximum straw yield, 8.48 ton ha^{-1}, which was statistically similar to those plots treated with NPS+K_{40} and NPS+K_{30} treatment. The treatment T7, i.e. NPS+K_{50}, revealed the best percentage of increased straw yield over control and the least was found in the no application of K fertilizer (T2).

Table 3. Effect of different treatments of K on grain and straw yields of BRRIdhan29

Treatments	Grain yield (ton ha^{-1})	%Grain yield increased over control	Straw yield (ton ha^{-1})	% Straw yield Increased over control
Control	3.27e	-	3.92f	-
RFD of NPS+K_0	4.02d	18.65	4.82e	18.67
RFD of NPS+K_{10}	4.32c	24.30	5.18cd	24.32
RFD of NPS+K_{20}	4.97bc	34.20	6.21c	36.87
RFD of NPS+K_{30}	5.70ab	42.63	7.12ab	44.94
RFD of NPS+K_{40}	6.79a	51.84	8.14a	51.85
RFD of NPS+K_{50}	7.07a	53.74	8.48a	53.78
SE (±)	0.53	-	0.65	-
CV (%)	27.6	-	27.57	-

Figures in a column having common letter(s) do not differ significantly at 5% levels of significance. CV: Coefficient of variation; SE (±): Standard error of means.

In a study, Ye et al. (2020) evaluated that the rice yield has high positive feedback on the K fertilizer application. This statement strongly supports our findings. The increasing rate of applied K fertilizer increased the grain yield of BRRI dhan29. The highest grain yield was recorded in T7 (RFD of NPS+K_{50}) while using the different fertilizers as a recommended dose. K is an essential element for the photosynthesis process with carbohydrate translocation and metabolism that can ultimately boost grain production (Pettigrew, 2008; Zorb et al., 2014; Lu et al., 2016). The increased grain yield might also be obtained because the K can provide resistance to many stress conditions and reduce grain sterility (Ma et al., 2019). The higher K dose also exerted a pronounced effect in producing a higher straw yield of the BRRI dhan29 variety. In our study, like grain yield, the K application with 50 kg ha^{-1} dose also brought out the highest straw yield. This might be because K increases rice strength, prevents lodging, and increases resistance to pest, which ultimately results in a higher yield of straw. Islam and Muttaleb (2016) in their field study observed that K enhanced rice crop grain and straw yield. They stated that K assists in improving the nitrogen uptake and its utilization, which can help in enhancing the rice yield. A similar result was also reported by Saha et al. (2007) and Saleque et al. (1998). Our study represented that the selected yield contributing factors significantly influenced and promoted rice grain yield. The higher K rate may be improved the overall quality of these factors, which finally enhances the grain yield (Atapattu et al., 2018).

Potassium content accumulation and uptake through rice grain and straw

The potassium (K) content that was available in the rice grain and straw after harvesting and K utilization by them were analyzed in this study. Both of these parameters were influenced by the K application (Table 4).

The K content in rice grain and straw depended on the K rate. The maximum K content was recorded in T7 (RFD of NPS+K_{50}) application for both grain and straw, which was 0.269% and 1.374%, respectively. However, there were no statistically significant differences in K content among T7, T6, T5 and T4 treatment applications.

It was found that compared with the control and K0 treatments, the K addition progressively boosted the K uptake by grain and straw. The K uptake by grain and straw varied from 4.77 to 19.01 kg ha^{-1} and 43.51 to

116.51 kg ha^{-1}, respectively. The highest K uptake was recorded from the rice grain and straw grown with 50 kg of K treatment application (T7). Here, Table 4 represents that treatment T7 and T6 (NPS with 50kg K and 40kg K, respectively) are statistically equivalent during K uptake through grain and straw of the selected rice variety. The total K uptake also demonstrated the same pattern.

Table 4. Effect of different treatments on K content and uptake by grain and straw of BRRI dhan29

Treatments	%K Content		K Uptake (kg ha^{-1})		Total K Uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
T1: control	0.146d	1.110e	4.77g	43.51e	48.28e
T2: RFD of NPS+K_0	0.253c	1.363d	10.17f	65.69d	75.86d
T3: RFD of NPS+K_{10}	0.256b	1.366bc	11.05de	70.75c	81.80c
T4: RFD of NPS+K_{20}	0.259a	1.368ab	12.87cd	84.95b	97.82b
T5: RFD of NPS+K_{30}	0.264a	1.371ab	15.04bc	97.61b	112.65b
T6 : RFD of NPS+K_{40}	0.267a	1.373a	18.13ab	111.87a	130.00a
T7: RFD of NPS+K_{50}	0.269a	1.374a	19.01a	116.51a	135.52a
SE(±)	0.016	0.037	1.86	9.96	11.82
CV (%)	17.95	7.35	37.94	31.22	32.10

Figures in a column having common letter(s) do not differ significantly at 5% levels of significance. CV: Coefficient of variation; SE (±): Standard error of means.

K content and uptake in rice grain and straw were significantly influenced due to different levels of K application. With the increase of K application, the k concentration and uptake in rice grain and straw also raised significantly (Table 4). Saleque et al. (1998) also mentioned that the K content, and K uptake can enhance in rice with increasing K fertilization. The related result was also demonstrated by Ahsan et al. (1997). Our results exhibited that the K content and uptake were always higher in straw than in grain.

Conclusion

Grain and straw yield, K content and uptake, and all the other yield contributing properties of the BRRI dhan29 rice variety were improved by the K application. The highest grain yield of 7.07 ton ha^{-1} and straw yield of 8.48 ton ha^{-1} of rice were recorded in RFD of NPS+ 50 kg K ha^{-1}, which were statistically identical to those observed in treatment T6 (6.79 ton ha^{-1} and 8.14 ton ha^{-1} for grain and straw, respectively) having 40 kg ha^{-1} potassium application. From the result, it can be decided that 40 kg potassium application per ha and a recommended dose of NPS are suitable for getting a maximum yield of BRRI dhan29 rice at Old Brahmaputra Floodplain Soil. As the K fertilizer application rate depends on soil fertility status, crop variety and yield, substantial research in this field is needed to prescribe appropriate K rates to farmers of different regions.

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