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Potassium Fertilizer Effect on the Growth and Yield of Boro Rice in Old Himalayan Piedmont Plain Soil of Bangladesh

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ABSTRACT

Increasing cropping intensity increases nutrient mining from the soil, especially potassium (K), if nutrient management is not properly maintained. A field experiment was conducted at Hajee Mohammad Danesh Science and Technology University (HSTU) farm soil, Dinajpur district under the Agro Ecological Zone (AEZ 1) the Old Himalayan Piedmont Plain soil in Boro 2020-21 to evaluate the soil test-based K fertilizer application on Boro rice to increase rice yield as well as maintain soil fertility. Six potassium doses namely, K control, 50%, 75%, 100%, 125% and 150% of soil test based (STB) K, were tested with balanced doses of other chemical fertilizers. Rice growth, yield, and yield-contributing characters were recorded during the panicle initiation and maturity stages of rice, which were greatly influenced by potassium fertilizer application. The grain yield increased significantly with increasing K rates up to 100% STB dose, and excess K application did not show any yield advantage. The N, P and K uptake and the K use efficiencies were influenced largely by the right amount of K application. The optimum K fertilizer dose was around 106 kg K ha-1 for the deficient piedmont rice soil. The 100% STB K fertilization might be suitable for obtaining higher rice yield and maintaining soil fertility in the HSTU farm soil under the Old Himalayan Piedmont Plain of AEZ 1.

Keywords: Piedmont soil, potassium, rice, grain yield, K efficiencies.

INTRODUCTION

Rice (*Oryza sativa*) is the most extensively cultivated cereal crop in Bangladesh, which covers about 76% of the total cropped area (BBS, 2018), and occupies first position as staple food. To satisfy the demands for food due to both population growth and diet diversity, production improvement is an urgent issue. Rice yield is predicted to double by 2030 (Zhang *et al.*, 2018). Fertilizers are usually applied to soil to increase or maintain crop yields to meet the increasing demand for food. The need for K fertilizer in the last decade has increased sharply along with the increase in food demand (Hartati *et al.*, 2018). Potassium (K) is an essential plant nutrient that contributes to the quality and plant resistance to water stress because of lower transpiration, so that water consumption is low. Potassium's role in the process of transpiration or water transport within the plant body is as a regulator of cell osmotic potential (Taize *et al.*, 2010; Zhang *et al.*, 2019). Rice crop requires large quantities and a continuous supply of K for the heading growth stage after completion of the reproduction stage (Atapattu *et al.*, 2018). A requirement of 200-300 kg K2O ha^{-1} is necessary to obtain 5-10 t ha^{-1} of cereal crop yield (Atapattu *et al.*, 2018). Modern high-yielding rice varieties remove much higher amounts of K than phosphorus (P) or even nitrogen (N) (Choudhury *et al.*, 1997; Liu *et al.*,

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2009; Sharma *et al.*, 2013). It is essentially required to stabilize the yield at a higher level. Compared to N and P fertilizers, K fertilizer is often ignored by farmers, particularly in Asia (Li *et al.*, 2014). On the other hand, rice crops remove about 103 kg K for a yield level of 7.0 t ha^{-1} (FRG, 2018). Islam and Muttaleb (2016) reported that K fertilization significantly increased rice yield and also mentioned the optimum dose of K for rice cultivation ranged from 78 to 93 kg ha^{-1}. Rice crop removes about 100 kg K for a yield level of 5 t ha^{-1} (Saha *et al.*, 2009). The balanced use of organic and inorganic fertilizers is the best practice to maintain soil health and crop productivity (Sarkar *et al.*, 2017). The general recommendation of K fertilizer for rice is often less than 100 kg-ha^{-1}, which causes mining of soil K. The K reserve of any soil is certainly limited, and no soil can supply K to crops adequately for an indefinite period of time. Intensive cropping and the use of modern rice varieties for high yield caused heavy depletion of K in soils, particularly in the absence of K application. Most of the area of AEZ 1 (Panchagarh, Thakurgoan, and part of Dinajpur districts) is deficient in potassium, where the dominant land types are high land to medium high land. In both land types, the soil potassium status is low to medium. Light-textured soils of this area have low exchangeable K, and farmers use a low amount of K fertilizer. Increasing cropping intensity increased the K deficiency in those areas. Understanding of K supplying power of soil is necessary for judicious recommendation of K fertilizer, compromising economic return and maintaining soil K reserve. In AEZ 1, the dominant clay minerals are Mica and Chloride, which are inherently deficient in K. At present, a soil test-based fertilizer application method was suggested by FRG, BARC, (2024). The application of fertilizer following STB would benefit the respective areas of farmers. The present investigation aimed to evaluate the soil test-based K fertilizer application on Boro rice to increase rice yield as well as maintain soil fertility.

MATERIALS AND METHODS

The field experiment was conducted at Hajee Mohammed Danesh Science and Technology University (HSTU) farm, Dinajpur (AEZ 1: Old Himalayan Piedmont Soil) during the Boro 2020-21 season. Before setting the field experiment, the initial soil sample was collected from 0-15 cm depth in the respective field. The soil sample was mixed properly and dried in a shaded conditions. Then the soil sample was ground, sieved by a 10 mesh and analyzed for different physical and chemical properties in the laboratory. The soil of the experimental field was loamy in texture, having 45% sand, 40% silt, and 15% clay. The pH of the experimental field was 5.8 (moderately acidic), organic carbon 1.2% (low), total N 0.09% (very low), available phosphorus 12 mg kg^{-1} (low), exchangeable potassium 0.10 meq/100g soil (low), available sulfur 10 mg kg^{-1} (low), and available zinc 2 mg kg^{-1} (medium). The soil test-based fertilizer for each nutrient was calculated.

Six potassium rates, including control, were assigned in an RCB design with three replications. The individual plot size was 4m × 4m. The treatments were K control, 50% STB K (40 kg ha^{-1}), 75% STB K (69 kg ha^{-1}), 100% STB K (92 kg ha^{-1}), 125% STB K (115 kg ha^{-1}), and 150% STB K (138 kg ha^{-1}). The N-P-S and Zn were used @ 150-20-10 and 2 kg ha^{-1}, respectively. The tested variety was BRRI dhan88. Forty-day-old seedlings of BRRI dhan88 were transplanted, maintaining 20 cm × 20 cm spacing. Urea was applied in three equal splits; one-third as basal, one-third at 25 days after transplanting (DAT) and the rest one-third at 5 days before panicle initiation (PI) stage. Standard cultural practices were followed for raising the rice crop. All plots were surrounded by a 30 cm soil levee to avoid fertilizer contamination between plots. Plant samples were collected at the panicle initiation stage for plant height, tiller number per square meter, shoot weight, and for measuring nitrogen, phosphorus, and potassium content and uptake. At maturity, the crop was harvested manually from 5 m^2 from the middle of each plot at 15 cm above ground level for grain yield, 16 hills from each plot at ground level for tiller, panicle and total straw yield data. Grain yield was recorded at 14% moisture content, and straw yield on an oven-dry basis. Tiller and panicle number per square meter were recorded. Percent filled grain and unfilled grain were also documented.

Grain and straw samples were chemically analyzed in the Soil Science Division's laboratory, BRRI, to determine the nitrogen, phosphorus, and potassium content and uptake. The agronomic use efficiency, physiological use efficiency, partial factor productivity, and recovery use efficiency were calculated. All experimental data were statistically analyzed using STAR software.

RESULTS AND DISCUSSION

Plant growth and biomass yield at the PI stage of Boro rice

Potassium fertilization showed a significant effect on rice plant height, tiller m^{-2}, and shoot yield at the panicle initiation (PI) stage of Boro rice (Table 1). The tallest plant (105.29 cm) was observed in T_6 treatment, where 150% STB potassium fertilizer was applied, followed by T_5 treatment (103.88 cm), where 125% STB K was applied. Medium-tall plants were observed in the T_4 treatment (96.37 cm), where 100% STB K was applied, which was significantly shorter than T_6 and T_5. The reduced doses of K application shortened plant height significantly, and the shortest plant (73.19 cm) was observed in the K control plot; i.e., in T_1. Nitrogen and K have a synergistic effect to increase plant height. The tiller m^{-2} was also influenced significantly by the application of K at different rates (Table 1). The number of effective tillers increased with the increasing potassium doses. The maximum tiller m^{-2} (405) was observed where the highest dose of K was applied. On the other hand, with decreasing K doses, tiller number decreased significantly. The minimum tiller number was found in the K control treatment. Similar findings were also reported by Kalita *et al.* (2002). It was evident that shoot biomass was significantly influenced by potassium application. Shoot weight increased gradually with increasing the K doses. Significantly higher shoot yield was obtained in T_4 (100% STB-K), which was statistically similar to T5 (125% STB-K) and T_6 (150% STB-K) treatment (Table 1). Significantly lower shoot yield was obtained with T_2 treatment (5.12 t ha^{-1}), where 75% STB-K was applied, and the K control (T_1) treatment performed the lowest (4.75 t ha^{-1}) shoot yield. This finding is at per with the results reported by Islam *et al.*, (2015).

Table 1. Effect of potassium fertilizer on plant height, tiller number and shoot yield in panicle initiation (PI) stage of BRRI dhan88 in Boro 2020-21 season at HSTU farm, Dinajpur.

Treatment	Plant height (cm)	Tiller No. (m^{-2})	Shoot yield (t ha^{-1})
T_1 = K control	73.19	342	4.75
T_2 = 50% STB K	85.73	374	5.12
T_3 = 75% STB K	92.56	384	5.34
T_4 =100% STB K	96.37	389	5.44
T_5 = 125% STB K	103.88	396	5.56
T_6 = 150% STB K	105.29	405	5.59
LSD (0.05)	7.32	28	0.28
CV (%)	2.78	2.61	1.89

N.B. T_1 = 0, T_2 = 40, T_3 = 69, T_4 = 92, T_5 = 115, T_6= 138 kg K ha^{-1}, respectively

Shoot N, P, and K uptake at the PI stage of Boro rice

The nitrogen, phosphorus, and potassium uptake by the shoot at the panicle initiation stage of Boro rice are illustrated in Table 2. The N uptake increased significantly with increased K doses. Although the highest N uptake (65.49 kg N ha^{-1}) was found in T_6 treatment, where 150% STB-K was applied but the result was insignificant with other K doses. The N uptake was lowest (50.87 kg N ha^{-1}) in the K control treatment. Actually, a synergistic effect was observed between N uptake and K doses. The highest shoot P uptake (12.97 kg P ha^{-1}) was obtained in T_5 treatment, where 125% STB-K was applied, but the result was not significantly higher with the application of other K treatments. The significantly lowest shoot P uptake (9.50 kg P ha^{-1}) was found in the K control treatment. Actually, K fertilizer had a good impact on increase K uptake of rice at the panicle initiation stage. Potassium fertilizer application greatly influenced the K uptake of rice shoots at the panicle initiation stage (Table 2). The highest K uptake (135.93 kg K-ha^{-1}) in the shoot was observed in the T_6 treatment (150% STB-K), which was statistically similar to the T_5 (130.78 kg K ha^{-1}) treatment (125% STB-K). The 100% STB-K (T_4) produced significantly lower K uptake than the T_5 and T_6 treatments. The other lower K doses, i.e., T_3 (75% STB-K) and T_2 (50% STB-K) treatment, gave significantly lower K uptake in the shoot at the PI stage of rice than T_4 (100% STB-K). The significantly lowest K uptake (75.72 kg K ha^{-1}) was achieved in T_1 treatment, where no K fertilizer was applied for rice production in the Boro season. The N, P, and K uptake was maximum at the panicle initiation stage of rice as reported by Payman *et al.,* (2017).

Table 2. Effect of potassium on shoot N, P, and K uptake at PI stage of BRRI dhan88 in Boro 2020-21 season at HSTU farm, Dinajpur.

Treatment	Shoot N uptake (kg ha^{-1})	Shoot P uptake (kg ha^{-1})	Shoot K uptake (kg ha^{-1})
T_1 = K control	50.87	9.50	75.72
T_2 = 50% STB K	57.20	11.28	95.95
T_3 = 75% STB K	61.26	12.29	110.25
T_4 =100% STB K	63.11	12.88	119.56
T_5 = 125% STB K	65.23	12.97	130.78
T_6 = 150% STB K	65.49	12.86	135.93
LSD (0.05)	4.83	1.47	11.39
CV (%)	2.81	4.34	3.61

N.B. T_1 = 0, T_2 = 40, T_3 = 69, T_4 = 92, T_5 = 115, T_6= 138 kg K ha^{-1}, respectively.

Growth, yield, and percent sterility at the maturity stage of rice

At maturity or harvest stage, tiller number per square meter and panicle number per square meter, grain yield and straw yield, and percent sterility were influenced significantly with the application of different K doses (Table 3). Regarding tiller production, the highest tiller number per square meter was found in the T_6 (150% STB-K) treatment, but it was statistically similar to T_5 (125% STB-K), T_4 (100% STB-K), and T_3 (75% STB-K) treatments. Significantly lower tiller was obtained with T_2 (50% STB-K) treatment, and the lowest tiller per square meter was in T_1 (without K fertilizer). The number of panicles per square meter also increased significantly with increasing doses of K at the maturity stage of rice (Table 3). The highest panicle number was observed in T_6 (401) treatment, where 150% STB-K was applied, but the result was statistically similar to that obtained in T_5 (398) and T_4 (386) treatment, where 125% STB-K and 100% STB-K were applied, respectively. The T_3 (75% STB-K) and T_2 (50% STB-K) treatments gave significantly lower panicle numbers than T_4, and the lowest panicle number was observed in the K control (346) treatment (T_1). Increasing potassium rates resulted in the longest panicle of rice, which could bear a higher number of spikelets per panicle. It was supported by Zayed *et al.* (2007). Grain yield, straw yield, and percent filled grain were influenced significantly by the application of K doses at different rates on a soil test basis in the Boro rice of BRRI dhan88 (Table 3). The K control plot yielded only 5.52 t ha^{-1} grain, and with the application of K fertilizer, the grain yield increased significantly. Grain yield increased with the increasing in potassium level up to T_6 and thereafter decreased. The grain yield significantly increases with increasing the K rates up to 100% STB, and further increasing the K rates, grain yield remains more or less similar and static. The highest grain yield was obtained with T_4 (7.91 t ha^{-1}) treatment, where 100% STB-K was applied, but the result was statistically identical with T_5 (7.83 t ha^{-1}) and T_6 (7.73 t ha^{-1}) treatment, where 125% and 150% STB-K were applied, respectively. The T_3 treatment (75% STB-K) gave significantly lower grain yield (7.39 t ha^{-1}) than T_4 (7.91 t ha^{-1}). Potassium fertilization influenced grain yield due to the assimilation of carbohydrates increased from source to sink. Increase in grain yield for the application of K was mainly due to improvement in yield components, i.e., number of effective tillers, panicle length, and grains per panicle. The highest grain yield was recorded in T_4 because of the highest number of effective tillers and the maximum number of grains per panicle also produced by T_4, which was significant with other higher K doses. Several workers reported a significant response of the grain yield of rice to the application of potassium (Bahmanyar and Mashaee, 2010). Saha *et al.* (2009) reported that application of chemical K fertilizer or rice straw increased the grain and straw yield of rice in Boro-Fallow-T. Aman cropping pattern in Modhupur Tract soil of AEZ-28. Saha *et al.* (2010) also reported that application of K @ 66 $kgha^{-1}$ for rice wheat pattern was not adequate and needed to increase the K dose for better K reserve in soil. It was evident that straw yield was significantly influenced by potassium rates, and it was the highest (8.03 t ha^{-1}) in T_6, and the lowest straw yield was obtained in T_1 (5.56 t ha^{-1}) treatment (Table 3). The higher K doses gave comparatively higher straw yield, and the result was statistically similar among T_3 to T_6 treatments. Significantly lower straw yield was observed in the T_2 treatment, where 50% STB-K was applied. All the treatments produced significantly higher straw yield than the K control treatment. Grain filling also increased due to proper K fertilization. The percent filled grain increased sharply with the application of K fertilizers at different rates. Actually, all the K-fertilized plots gave statistically similar filled grain percent over the K control plot (Table 3). Here, it was clear that K fertilization increased the number of filled grains in the panicle and thus yield increased. A similar result was found by Krishnappa *et al.* (2006) and who reported that applying K increased the number of filled grains per panicle. Basal application of K fertilizer showed a positive effect on the percentage of filled grains. Potassium helped in proper filling of seeds, which resulted higher number of plump seeds and thus increased the number of grains per panicle. Esfehani *et al.* (2005) showed that potassium fertilizer has positive effects on filled grains in rice, while its deficiency causes pollen sterility and decreases the number of filled grains per panicle.

Table 3. Response of BRRI dhan88 to potassium fertilizer on tiller and panicle production, grain and straw yield, and % filled grain in Boro 2020-21 season at HSTU farm, Dinajpur.

Treatment	Tiller m^{-2}	Panicle m^{-2}	GY (t ha^{-1})	SY (t ha^{-1})	Filled grain (%)
T_1 = K control	363	346	5.52	5.56	82.07
T_2 = 50% STB K	390	372	7.07	7.15	85.61
T_3 = 75% STB K	404	379	7.39	7.46	86.66
T_4 =100% STB K	414	386	7.91	7.97	87.23
T_5 = 125% STB K	423	398	7.83	8.00	87.63
T_6 = 150% STB K	425	401	7.73	8.03	87.78
LSD (0.05)	24	20	0.49	0.59	2.85
CV (%)	2.07	1.89	2.39	2.83	1.17

T_1 = 0, T_2 = 40, T_3 = 69, T_4 = 92, T_5 = 115, T_6= 138 kg K ha^{-1}, respectively.

Total N, P, and K uptake at the maturity stage of Boro rice

The total N uptake by rice (grain and straw) at the maturity stage was significantly influenced by the application of different doses of STB-K fertilizer in rice in the Boro season. Although higher N uptake was found in T6 (150% STB-K) but the result was statistically similar to that obtained in T_5 (125% STB-K) and T_4 (100% STB-K) treatment (Table 4). Nitrogen uptake at maturity was significantly lower in those treatments where K fertilizer was used below the 100% STB level. The total P uptake by rice (grain and straw) at the maturity stage was also significantly influenced by the application of different doses of STB-K fertilizer. Although higher P uptake was found in T_6 (150% STB-K) but the result was statistically similar to that obtained in T_5 (125% STB-K), T_4 (100% STB-K), and T_3 (75% STB-K) treatment (Table 4). The total P uptake was significantly lower in those treatments where K fertilizer was used below the 75% STB level. Significantly less P uptake was obtained in the K control treatment. The total K uptake by rice (grain and straw) at the maturity stage was also significantly influenced by the application of different doses of STB-K fertilizer in Boro rice (Table 4). The highest K uptake (193 kg ha^{-1}) in grain and straw was obtained in T_6 (150% STB-K), and the lowest K uptake (90 kg ha^{-1}) was in T_1 (K control). Although higher K uptake was found in T_6 (150% STB-K) but the result was statistically similar to that obtained in T_5 (125% STB-K) and T_4 (100% STB-K) treatment (Table 4). Potassium uptake was significantly lower in those treatments where K fertilizer was used below the 100% STB level. Application of K significantly increased the straw K content and total K uptake of both wheat and rice crops as reported by Saha *et al.* (2008). The potassium uptake was much higher than the nitrogen and phosphorus uptake by rice. Hossain *et al.* (2013) also reported that application of soil test based inorganic K (STB-K) fertilizer increased the grain yield of wheat as well as total N, P, and K uptake in Old Himalayan Piedmont Plain Soil of AEZ^{-1}.

Potassium use efficiency of rice

Application of K fertilizer in rice field in Old Himalayan Piedmont Plain Soil, i.e., in AEZ^{-1} in Boro season, greatly influenced the K use efficiencies. The agronomic efficiency (AE) (kg grain yield increased per kg of applied K) decreased with increasing K levels (Table 5). The higher AE were observed in lower doses of K application. A similar trend was also found in the case of partial factor productivity for applied K (PFP-K) and recovery efficiency of K (RE-K). Nevertheless, the physiological efficiency of K (PE-K) was almost the same level regardless of K application (Table 5). Agronomic use efficiency of K, partial factor productivity and recovery efficiency of K decreased with the increase of K levels. A similar result was obtained by Saha *et al.* in 2008, who also reported that the AE, PFP, RE, etc., were decreased with increased K fertilizer doses.

Table 4. Response of BRRI dhan88 to potassium fertilizer application on N, P and K uptake in Boro 2020-21 season at HSTU farm, Dinajpur.

Treatment	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})	Total K uptake (kg ha^{-1})
T_1 = K control	74.14	12.84	90.06
T_2 = 50% STB K	99.82	18.84	139.05
T_3 = 75% STB K	108.96	20.89	159.87
T_4 =100% STB K	119.24	23.24	179.68
T_5 = 125% STB K	121.53	23.13	187.10
T_6 = 150% STB K	121.99	23.71	192.99
LSD (0.05)	5.42	3.84	19.13
CV (%)	1.78	6.62	4.27

N.B. T_1 = 0, T_2 = 40, T_3 = 69, T_4 = 92, T_5 = 115, T_6= 138 kg K ha^{-1}, respectively

Table 5. Influence of K fertilization on different potassium use efficiencies of Boro rice of BRRI dhan88 at HSTU, Dinajpur.

Treatment	PFP-K	AE-K	PE-K	RE-K
T_1= K control	-	-	-	-
T_2= 50% STB-K	177	39	31.64	122
T_3= 75% STB-K	107	27	26.79	101
T_4= 100% STB-K	86	26	26.67	97
T_5= 125% STB-K	68	20	23.80	84
T_6= 150% STB-K	56	16	21.47	75

PEP-K = Partial factor productivity of K, AE-K = Agronomic efficiency of K, PE = Physiological efficiency of K, RE-K (%) = Recovery efficiency of K.

CONCLUSION

Potassium is becoming the second most limiting nutrient for crop production in many parts of Bangladesh, including AEZ 1. Potassium fertilizer increased grain yield with increasing rate of K up to 100% STB dose. The 100% STB-K (92 kg ha^{-1}) performed the best in terms of rice yield. From the quadratic equation of the response curve, the economic optimum dose of K was found to be 106 kg ha^{-1}, which is almost closer to the STB dose; therefore, soil test-based fertilizer should be applied for optimum rice production in those areas. As the Old Himalayan Piedmont Plain Soil of AEZ 1 is inherently

K-deficient, potassium fertilizer must be used judiciously to obtain higher rice yield and maintain soil K supplying capacity. More research work should be conducted on K fertilizer management in different rice-based cropping patterns and locations of the piedmont soils of AEZ 1.

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