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Effects of Potassium Fertilization on Growth and Yield of Wetland Rice in Grey Terrace Soils of Bangladesh

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ABSTRACT

Variable rates (0, 20, 40, 60 and 80 kg ha^{-1}) of potassium (K) fertilization effects on growth, yield as well as the relationship between yield and growth parameters of T. Aman (monsoon season) rice were examined in 2010 at Bangladesh Rice Research Institute (BRRI) research farm, Gazipur, Bangladesh following randomized complete block design with three replications. Test rice variety was BRRI dhan49 and the soil was Aeric Haplaquept. Plant height, panicle length, dry matter production at maturity, straw and grain yields significantly ($p < 0.01$) increased in a quadratic fashion; but tillersm^{-2}, panicles m^{-2}, spikelet panicle^{-1}, filled grains in a panicle, dry matter yield at panicle initiation (PI) stage increased significantly ($p < 0.01$) in a linear fashion when K rates were increased from 0 to 80 kg ha^{-1}. Maximum grain yield (4958 kg ha^{-1}) was obtained at 80 kg K ha^{-1}. Panicles m^{-2}, spikelets in a panicle, filled grains, dry matter yield, harvest index, 1000 grain weight had significant positive association with grain yield. Optimum K rate and K requirement of BRRI dhan49 was found to be 64.14 kg ha^{-1} 13 kg t^{-1} rice. Calculated K dose for T. Aman rice was much higher than the recommended dose. Therefore, potassium dose for wet season rice should be increased for desired yield otherwise potassium mining from soil and yield reduction might be occurred.

Keywords: Yield component, Dry matter, Harvest index, Association

INTRODUCTION

In Bangladesh, rice is grown in Aus (pre-monsoon, April to June), Aman (Monsoon, July to November) and Boro (dry season irrigated, December to June) seasons. Five fertilizers are generally use for cultivation of rice (Shah *et al.*, 2008) of which K is required for plant growth and fecundity (Rengel and Damon, 2008; Fageria *et al.,* 2011). Lack of K restricts the establishment, development, and yield of crops (Rengel and Damon, 2008). Potassium is required for the activity of many enzymes, including those of energy metabolism, protein synthesis, and solute transport. Also it contributes significantly to cell turgor, especially in rapidly expanding cells, and acts as a counter cation for anion accumulation and electrogenic transport processes (Amtmann *et al.*, 2006: White and Karley, 2010).

Rice plants absorb K in larger quantities even than nitrogen for proper function of various activities. Modern high-yielding rice varieties remove much higher amount of K than phosphorous (P) or even nitrogen (N) (Choudhury *et al.*, 1997; Liu *et al.*, 2009; Sharma *et al.*, 2013). On the other hand, rice crops remove about 103 kg K for a yield level of 7.0 t ha^{-1} (FRG, 2012). It is essentially required to stabilize yield at a higher level. Compared with N and P fertilizer, K fertilizer is often ignored by farmers, particularly in Asia (Li *et al.*, 2014). The previous idea about the sufficiency of K in soils of Bangladesh might be true for local crop varieties that produced about 3 t ha^{-1} from rice-wheat or rice-rice rotation systems (Islam, 2009), but this is not enough to feed the nation. 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}.

General recommended dose of K for Grey terrace soils of Bangladesh to cultivate modern rice varieties with yield potential of 4.5-5.5 t ha^{-1} is only 35 kg ha^{-1} (FRG, 2012). This lower K dose is not competent to replenish soil K levels quickly to meet the maximum demand of rice crops. As a result rice plants suffer from K deficiency and become more susceptible to biotic and abiotic stresses irrespective of other nutrients supplied (Johnston *et al.,* 2001).

Farmers in Bangladesh are generally not interested to apply K fertilizer or they use very small quantity for rice cultivation because its visible effect is not recognized by them. Moreover, farmers are not efficient enough to identify K deficiency symptom of rice plant. For this reason, intensive cropping with increased N and P fertilizers, yield response of rice to K fertilization becomes more evident (Yang *et al.*, 2003). Potassium fertilization ensures proper root growth and uptake of other nutrients, which ultimately increase the crop growth and development. Response of T. Aman rice, especially BRRI dhan49 to K fertilization has not been well documented in Bangladesh. So, a field experiment was conducted during T. Aman season 2010 in a permanent layout of BRRI farm after 15 seasons of K management with different levels of K application to examine the impact of K fertilization on growth and yield, to determine the optimum K fertilizer rate, and to study the relationships between growth parameters and yield of rice.

MATERIALS AND METHODS

Soil, Crop, Experimental Design and Treatments

The experiments were conducted in the research field of BRRI farm, Gazipur in a permanent layout of long-term K management experiment first designed in Boro (dry season), 2003. The long-term K management experiment received K application from 0 to 80 kg ha^{-1} $season^{-1}$, with an interval of 20 kg ha^{-1}, for 15 seasons in 8 years. Soil properties of experimental field (initial and after 15 crop seasons) are shown in Table 1.

The soil of the experimental field was Aeric Haplaquept. In T. Aman 2010 season (16th season), a popular rice variety BRRI dhan49 was tested with five K doses: 0, 20, 40, 60, and 80 kg K ha^{-1} designated as K_0, K_{20}, K_{40}, K_{60} and K_{80}, respectively. A flat dose of N, P and sulphur (S) at 97, 15 and 14 kg ha^{-1}, respectively was applied in each plot. Dates of seeding, transplanting and harvesting were 26.06.2010, 25.07.2010, and 13.11.2010, respectively. The experimental design was randomized complete block with three replications. Nitrogen, P, K, and S were applied as urea, triple super phosphate, muriate of potash (source of K) and gypsum, respectively. One-third of N and the whole amounts of P, K and S were applied at final land preparation. The remaining two-third N was applied in two equal splits at 25-30 days after transplanting (DAT) and 7 days before PI stage. Two rice seedlings (35 day-old) were transplanted in a hill with 20 cm × 20 cm spacing. Irrigation water was applied as needed. Standard cultural and management practices including plant protection measures were followed during each growing season. Unit plot size was 16.9 m × 3.6 m. All plots were surrounded by 30 cm soil levees to avoid contamination.

Data Collection and Analysis

Above ground dry matter yield at PI stage, flowering stage (initiation, 50% flowering and 80% flowering), plant height, tillers and panicles m^{-2}, panicle length, grains per panicle, sterility percentage and 1000-grain weight were recorded. At maturity, the crop was harvested from 5 m^2 areas manually at 15 cm above ground level; however, 16 hills from each plot were harvested at the ground level for straw yield data. Grain yield was recorded at 14% moisture content and straw yield as oven dry basis. Harvest index (HI) was computed as:

$$HI = \left(\frac{\text{Grain yield}}{\text{Grain yield} + \text{Straw yield}} \right) \times 100$$

Analysis of variance (ANOVA) was performed with CropStat for Windows Version 7.2.2007.3. Differences among treatments means of the studied parameters were judged by least significant difference (LSD) at $p \leq 0.05\%$ level of significance. Regression analysis performed with MS Excel program.

Table 1. Soil properties of experimental plot, BRRI farm, Gazipur, 2003-2010

Soil parameters	Method	Initial	After 15 crops	
			K_0	K_{80}
Texture	Hydrometer method	Clay-loam	Clay-loam	Clay-loam
pH (1:2.5)	Glass electrode method	5.70	5.97	6.06
Organic C (%)	Wet digestion method	0.72	0.81	1.08
Total N (%)	Micro-Kjeldahl method	0.07	0.09	0.12
Available P (ppm)	Modified Olsen method	9.29	15.10	13.70
Available K (cmol kg^{-1})	N NH_4OAc method	0.18	0.13	0.17
Available S (ppm)	CaH_2PO_4 extraction	5.39	7.40	8.90
Available Zn (ppm)	DTPA extraction	3.65	4.30	4.10

Calculation of K Dose

A quadratic relationship was established between applied K rate and yield of rice to estimate maximum K rate (K_{max}) and economic optimum K rate (K_{opt}) for rice by following equations (Gomez and Gomez 1984):

$$K\max = \left(\frac{-\mathrm{b}}{2\mathrm{c}}\right)$$

where b and c are the numerical constants in quadratic equation of response functions.

$$Kopt = 1/2c\left(\frac{\mathrm{Pf}}{Py} - b\right)$$

where Pf and Py are prices of K (Tk.30 kg^{-1}) and rice grain (Tk.20 kg^{-1}), respectively.

RESULT

Plant Height

Application of K significantly influenced plant height of BRRI dhan49 at maturity stage (Table 2). Potassium control (K_0) plot showed a plant height of 95 cm, which increased progressively up to 113.93 cm with 80 kg K ha^{-1}. Application of 60 kg K ha^{-1} gave statistically identical plant height (111.60 cm) with K_{40}, while K_{60} and K_{80} treatments gave statistically similar plant height. Plant height showed a quadratic response with K rates (Figure 1). Added K explained 86.91% of the variability in plant height of BRRI dhan49.

$$y = -0.0022x^2 + 0.4073x + 95.244 \quad ,R^2 = 0.8691^{**} \qquad (1)$$

where y = plant height in centimeter and x = rates of potassium application (kg ha^{-1}).

Table 2. Effect of K doses on some plant parameters of T. Aman rice (BRRI dhan49), BRRI, Gazipur, 2010

Treatment	Plant height (cm)	Tiller m^{-2}	Panicle m^{-2}	Panicle length (cm)
K_0	95.33	259	248	21.17
K_{20}	102.20	280	263	22.66
K_{40}	108.47	285	264	23.23
K_{60}	111.60	302	290	23.27
K_{80}	113.93	325	301	24.25
LSD $_{0.05}$	4.43	10	10	1.18
CV (%)	2.20	2.00	2.00	2.70

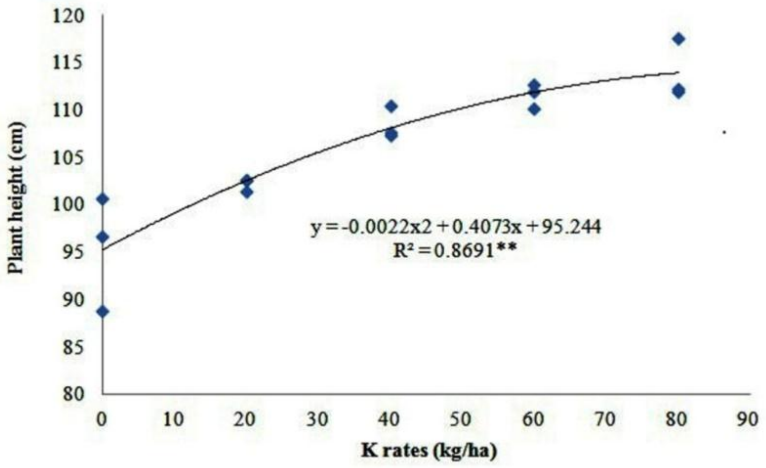

Figure. 1. Relationship between different K levels and plant height, T. Aman, 2010, BRRI, Gazipur.

Number of Tillers and Panicles

Production of tillers was significantly influenced by different K rates at maturity (Table 2). K_0 treatment gave the lowest (259) tillers m^{-2}, which increased significantly up to 325 m^{-2} with K_{80}. There were similar tiller production with K_{40} and K_{20}, but K_{60} treatment gave significantly higher tiller m^{-2} compared to K_{40} rate. Same trend was observed in case of panicle production. Panicle production was the lowest in K_0 plot (248 panicle m^{-2}), which increased significantly to 263 with K_{20} and 264 with K_{40}. With increasing K rates, panicles production further increased to 301 m^{-2} with K_{80}. Effects of applied K on tiller and panicle production can be explained by equations 2 and 3, respectively. Tiller and panicle production with increasing K rates were linear (Figure 2). About 87% and 69% of the variabilities in tiller and panicle productions were associated with K fertilization.

$$y = 0.7656x + 259.69 \quad , \quad R^2 = 0.8688^{**} \qquad (2)$$

$$y = 0.6667x + 246.56 \quad , \quad R^2 = 0.6949^{**} \qquad (3)$$

where y = number of tillers or panicles and x = rates of K application.

This result indicated that there is a scope to increase tiller and panicle production with K application beyond 80 kg ha^{-1}. Jacqueline *et al.* (2008) reported linear fashion of tiller and panicle production with increasing N level in lowland rice.

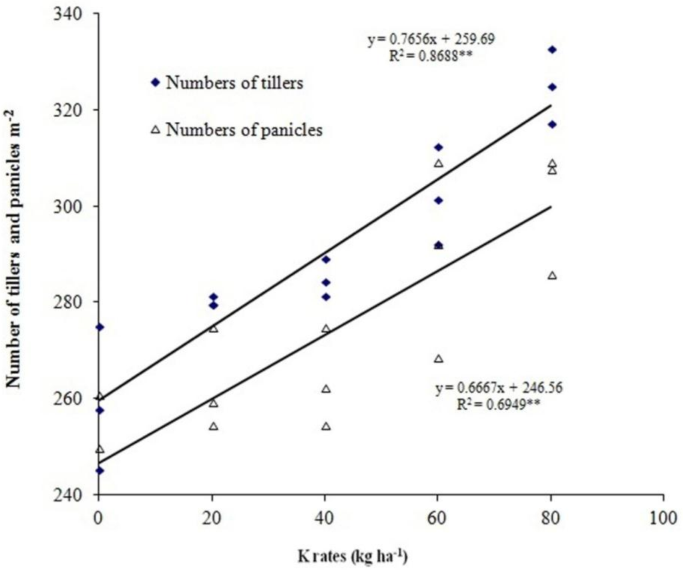

Figure 2. Relationship between different K levels and number of tiller and panicle production, T. Aman, 2010, BRRI, Gazipur

Panicle Length

Potassium application significantly increased panicle length of BRRI dhan49 (Table 2). K_0 treatment gave the smallest panicle of 21.17 cm, which increased significantly to 22.66 cm with K_{20}. Increasing K rates to K_{20}, K_{40} and K_{60} produced statistically identical sized panicle. Effects of added K on panicle length can be best described by equation 4 that explained 52.30% of the variability (Figure 3).

$$Y = -0.0003x^2 + 0.0558x + 21.344 \ , \ R^2 = 0.5230^{**} \qquad (4)$$

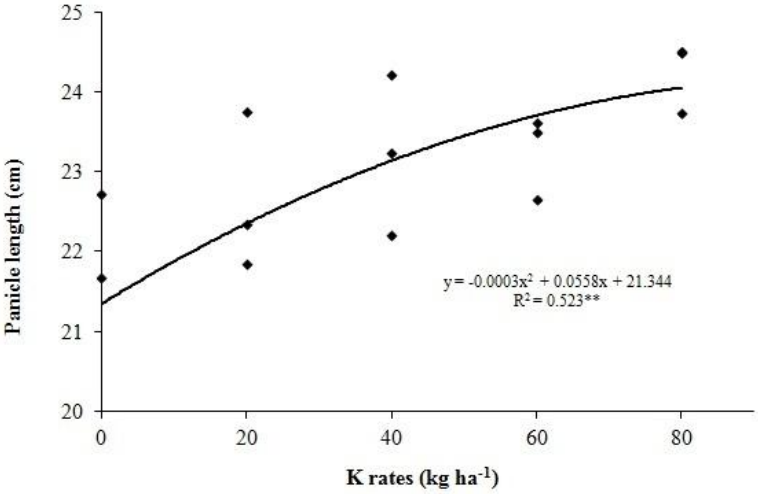

Figure. 3. Relationship between K rates and panicle length, T. Aman 2010, BRRI, Gazipur.

Days to Flowering

Application of K significantly influenced the flowering behavior (Table 3). It took 111 days for flowering in absence of K application. Moreover, application of K at 20 kg ha^{-1} did not influence flowering initiation, but the onset of flowering was one day earlier with 40 kg K ha^{-1}. The initiation of flowering in K_{60} and K_{80} was 3 days earlier than K-control plot. The trend of 50% and 80% flowering with K fertilizer application followed same pattern as observed in flowering initiation.

Table 3. Effect of different K doses on days to flowering, T. Aman 2010, BRRI, Gazipur

Treatment	Flowering		
	Starts	50%	80%
K_0	111	115	118
K_{20}	111	115	117
K_{40}	110	113	116
K_{60}	108	111	116
K_{80}	108	111	114
LSD $_{0.05}$	0.64	1.14	0.94

Numbers of Spikelets

Application of K significantly increased the number of spikelets panicle^{-1} in T. Aman rice. (Table 4). The number of spikelets panicle^{-1} was only 115 in K_0 treatment while the application of 20 kg K ha^{-1} increased the number of spikelets to 152. The increasing of K rate to 40 kg ha^{-1} increased the number of spikelets per panicle to 172. The highest (209) number of spikelets panicle^{-1} was recorded in K_{80} treatment which was significantly different from other treatments. Effects of applied K fertilizers on the spikelets per panicle of BRRI dhan49 can be best described by linear Equation 5 which accounted for 80.51% of the variability (Figure 4).

$$y = 1.0613x + 122.19 \ , \qquad R^2 = 0.8051^{**} \qquad (5)$$

where y = spikelets per panicle and x = rates of potassium application (kg ha^{-1}).

Filled Grains

Potassium application significantly influenced the filled grain panicle^{-1} (Table 4). K_0 treatment produced the lowest filled grains of 99 panicle^{-1} which increased to 132 panicle^{-1} with K_{20} treatment. Application of 40 kg K ha^{-1}, showed 150 filled grains per panicle. With the increasing of K rates, the filled grain per panicle progressively increased to 185 with the K_{80} treatment. Any level of K application produced significantly higher filled grain than K_0 treatment. However, K_{20} and K_{40} treatments produced statistically identical filled grain while the K_{40} and K_{60} treatments gave similar filled grain panicle^{-1}. Effects of applied K on the filled grains per panicle of BRRI dhan49 can be best described by linear Equation 6 which accounted for 79.39% of the variability (Figure 4).

$$y = 0.9793x + 105.09\ ,\qquad R^2 = 0.7939^{**} \qquad (6)$$

where y = filled grains per panicle and x = rates of potassium application (kg ha^{-1}).

Table 4. Effect of different doses of chemical K fertilizer on yield components, T. Aman 2010, BRRI, Gazipur

Treatment	Spikelet No./Panicle	Filled grain/Panicle	% unfilled grain	1000 grain wt (g)
K_0	115	99	14.11	18.61
K_{20}	152	132	13.66	19.20
K_{40}	172	150	12.32	19.51
K_{60}	176	156	11.76	19.77
K_{80}	209	185	11.44	19.86
LSD $_{0.05}$	22	19	NS	NS
CV (%)	7.00	7.20	10.1	2.80

Unfilled Grains and 1000-Grain Weight

Added K did not affect the % unfilled grain and 1000-grain weight significantly (Table 4). However, K application reduced the % unfilled grain and increased the 1000-grain weight to some extent. K_0 treatment showed the highest % unfilled grain of 14.11 which decreased to 13.66 with K_{20}, 12.32 with K_{40}, 11.76 with K_{60}. Application of 80 kg K ha^{-1} showed the lowest % unfilled grains of 11.44% in T. Aman rice. In case of 1000-grain weight, the K control plot showed the lowest 1000-grain weight of 18.61g which increased to 19.20g with K_{20} treated plot (Table 4). Increase of K rate to K_{40}, 1000-grain weight increased to 19.51g. Further increase of K rate, increased 1000-grain weight up to 19.86g in K_{80} treatment.

The effects of applied K fertilizers on the % unfilled grains per panicle and 1000-grain weight of BRRI dhan49 can be best described by linear Equations 7 and 8 (Figure 4).

$$y = -0.0362x + 14.105,\qquad R^2 = 0.2845^{*} \qquad (7)$$
$$y = 0.0153x + 18.775\ ,\qquad R^2 = 0.4832^{**} \qquad (8)$$

where y = filled grains per panicle, or % uniffiled grain per panicle, and x = rates of potassium application (kg ha^{-1}). Applied K could explain only 28.45 and 48.32% of the variability of % unfilled grain and 1000-grain weight, respectively in T. Aman rice.

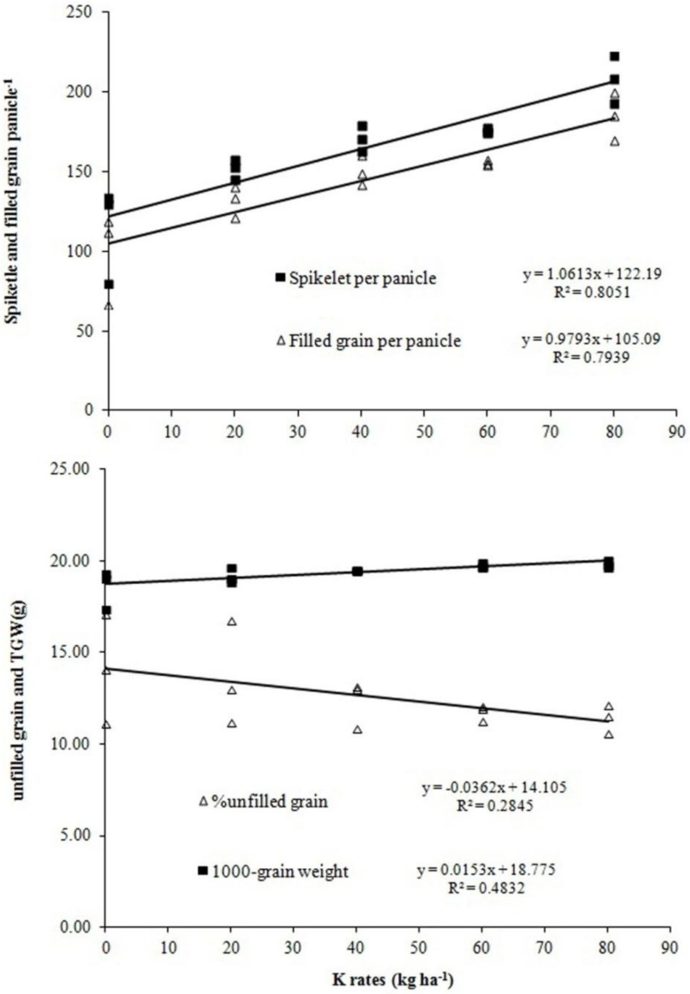

Figure 4. Relationship between K rates and spikelet per panicle filled, grain per panicle, % unfilled grain and 1000 grain weight (TGW), of T. Aman 2010, BRRI, Gazipur.

Dry Matter Yield at Panicle Initiation (PI) Stage

The data presented in Table 5 revealed a statistically significant increase in shoot dry matter production at PI stage due to different K treatments. K_0 treatment gave the lowest dry matter yield of 3610 kg ha^{-1} which increased to 4090 kg ha^{-1} with K_{20} treatment. By increasing of the K application to K_{40}, shoot dry matter yield increased to 4330 kg ha^{-1}. Shoot dry matter yield at PI stage progressively increased to 5210 kg ha^{-1} with K_{80} treatment. Application of 20 kg K ha^{-1} (K_{20}) did not produce significantly higher dry matter compared to K control. But K_{40} treatment gave statistically significant higher dry matter than K control. On the other hand, K_{20}, K_{40}, and K_{60} treatments produced statistically similar dry matter at PI stage in T. Aman season. However, K_{80} treatment gave significantly higher dry matter yield than K_{40} treatment but statistically identical with K_{60} treatment.

Potassium application linearly increased the shoot dry matter yield at PI stage and applied K accounted for 74.47% of the variability in shoot dry weight at PI stage (Figure 5). The following regression model best explained the relationship.

$$y = 18.762x + 3627.1 , \qquad R^2 = 0.7447^{**} \qquad (9)$$

where y = dry matter production and x = rates of potassium application (kg ha^{-1}).

Grain Yield

Application of K significantly increased grain yield of T. Aman rice (Table 5). K_0 treatment showed the lowest grain yield of 2778 kg ha^{-1} which increased to 4128 kg ha^{-1} with the application of 20 kg K ha^{-1}. Treatment K_{40} increased the grain yield from 4128 kg ha^{-1} to 4651 kg ha^{-1} which was statistically grain yield of 4767 achieved with K_{60} treatment. With the increasing of K rate grain yield of T. Aman rice progressively increased to 4958 kg ha^{-1} with K_{80} treatment. Application of 20, 40, 60 and 80 kg K ha^{-1} gave 1350, 1873, 1989 and 2180 kg ha^{-1} additional rice, respectively than K control treatment. On the other hand, K_{80} treatment produced about 1.79 fold higher grain over the K control plot. T. Aman rice (BRRI dhan49) yield responded quadratically at harvest to the applied K (Figure 5). The response of rice could be explained by the equations 10. Potassium application accounted of 94.39% of the variability of grain yield.

$$y = -0.4865x^2 + 63.912x + 2867.5 , \qquad R^2 = 0.9439^{**} \qquad (10)$$

where y = grain yield and x = rates of potassium application (kg ha^{-1}).

From the quadratic equation regarding the grain yield, the calculated K rate that maximized rice yield was 65.69 kg ha^{-1} and estimated yield would be 4967 kg ha^{-1}. The calculated K rate that maximized the profit i.e., the economic optimum dose of K for T. Aman rice BRRI dhan49 was 64.14 kg ha^{-1} and the estimated yield would be 4966 kg ha^{-1}.

Straw Yield and above Ground Biomass Production (AGBP)

Added K significantly affected the straw yield as well as AGBP (Table 5). K_0 treatment showed the lowest straw yield of 4430 kg ha^{-1} and AGBP of 7208 kg ha^{-1}. The K_{20} treatment increased the straw yield and AGBP to 5769 and 9897 kg ha^{-1}, respectively. By increasing of the K rate to K_{40}, the straw yield increased to 6603 kg ha^{-1} which was statistically identical with 6810 kg ha^{-1} obtained in $K_{60.}$ The highest K dose (K_{80}) gave the highest straw yield of 7121 kg ha^{-1} and it was statistically indifferent from K_{60} treatment. But in case of AGBP, each level of added K was significantly different from each other. The response of T. Aman rice to K fertilization regarding the straw yield and AGBP could be explained by the following quadratic equations (Figure 5). The K application accounted for 95.56 and 95.88% of the variability in straw yield and AGBP, respectively.

$$\text{Straw yield}, \qquad y = -0.4789x^2 + 70.4429x + 4478.7, \quad R^2 = 0.9556^{**} \qquad (11)$$

$$\text{Total AGBP}, \qquad y = -0.9654x^2 + 134.34x + 7346, \quad R^2 = 0.9588^{**} \qquad (12)$$

where y = straw yield or AGBP, and x = rates of potassium application (kg ha^{-1})

Table 5. Effect of different doses of chemical K fertilizer on the yield and harvest index, T. Aman 2010, BRRI, Gazipur

Treatment	DMP[1] (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain yield (kg ha^{-1})	AGBP[2] (kg ha^{-1})	Harvest index (%)
K_0	3610	4430	2778	7208	38.55
K_{20}	4090	5769	4128	9897	41.71
K_{40}	4330	6603	4651	11254	41.30
K_{60}	4650	6810	4767	11577	41.18
K_{80}	5210	7121	4958	12079	41.06
LSD $_{0.05}$	710	320	181	101	1.67
CV (%)	8.70	2.80	2.30	1.70	2.20

[1] DMP = Dry matter production at panicle initiation (PI) stage
[2] AGBP = Above ground biomass production at maturity

Grain Harvest Index (GHI)

Grain harvest indices significantly varied with K treatments (Table 5). Potassium control treatment showed the lowest GHI of 38.55% which increased to 41.71%, the highest GHI with K_{20} treatment. Whithin K_{20}, K_{40} and K_{60} and K_{80} treatments the grain harvest indices were not statistically apart from each other. The K_{20} produced the highest harvest index (41.71%) which was followed by K_{40} and K_{60} and K_{80} treatments.

The negative quadratic terms of the equation both for grain, straw and total above ground biomass yields indicated the decreasing rate of yield increment with the increasing rate of K. The decreasing trend was slightly higher for grain than for straw yield. From the value of slope, it could be speculated that more straw was produced than grain with per unit applied K. One kg of applied K produced 64 kg grain and 70 kg of straw. For this reason harvest index was slightly decreased with the increasing rate of K fertilizer (Table 5).

Growth Parameters and Yield Components Association with Grain Yield

Plant height showed significant positive linear association with grain yield (Figure 6) and was described by the equation 13.

$$y = - 6585.4 + 101.99x, \quad R^2 = 0.8495^{**} \tag{13}$$

Plant height explained 84.95% variability of the grain yield. Hence increasing plant height can increase the grain yield of lowland rice. Tiller and panicle m^{-2} had a significant quadratic association with grain yield (Figure 7) and the equations 14 and 15 expressed the quadratic models of the relationship. Tiller and panicle production described the variability of grain yield by 83.08% and 69.80%, respectively.

$$y = -0.416x^2 + 271.62x – 39308 \;, \quad R^2 = 0.8308^{**} \tag{14}$$

$$y = -0.5032x^2 + 305.33x – 41346 \;, \quad R^2 = 0.6980^{**} \tag{15}$$

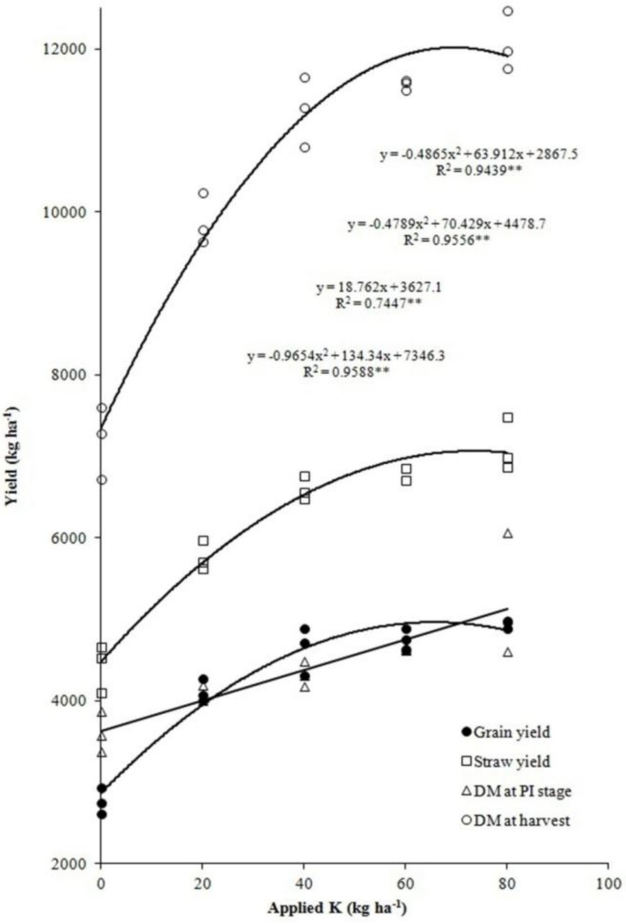

Figure 5. Relationship between K rates and grain yield, straw yield and dry matter (DM) production at PI and maturity stage, T. Aman 2010, BRRI, Gazipur.

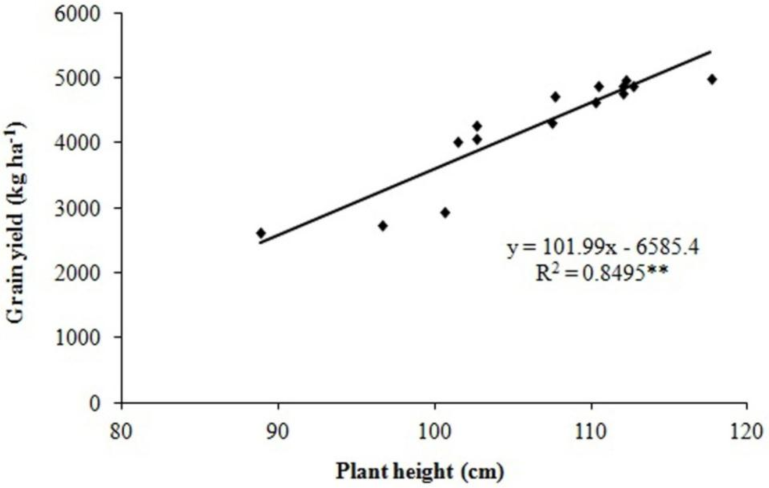

Figure 6. Relationship between plant height and grain yield, T. Aman 2010, BRRI, Gazipur.

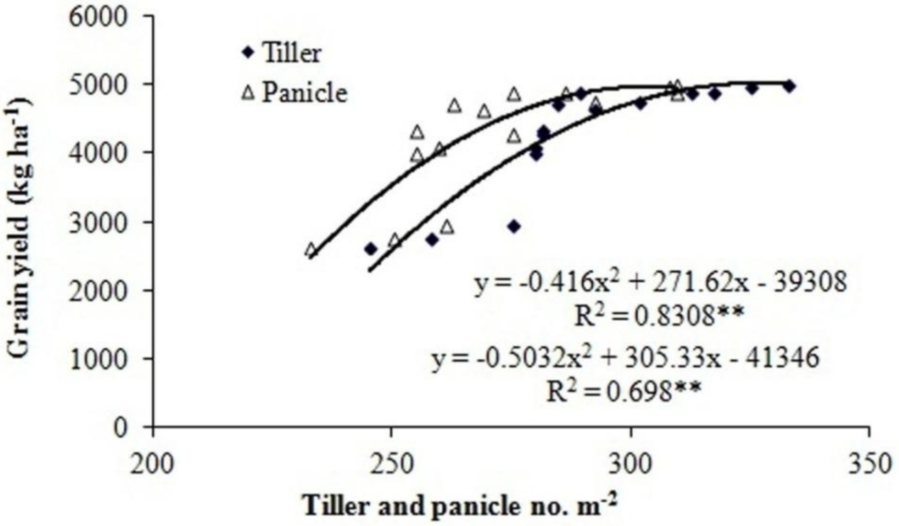

Figure 7. Relationship between tiller and panicle production and grain yield, T. Aman 2010, BRRI, Gazipur.

A positive quadratic association between spikelet per panicle and grain yield of T. Aman rice was observed (Figure 8). The fitted regression model could be described by the equation no. 16. Number of spikelets per panicle accounted for 81.84% of the variability of T. Aman rice grain yield.

$$y = -0.0483x^2 + 36.396x - 371.38, \qquad R^2 = 0.8184^{**} \qquad (16)$$

Grain yield of T. Aman rice increased quadratically with the increase in filled grains per panicle (Figure 8). The fitted regression model was described by the equation 17. Number of filled grain per panicle accounted for 80.59% of the variability of grain yield of T. Aman rice.

$$y = -0.0585x^2 + 38.736x – 57.88 , \qquad R^2 = 0.8059^{**} \quad (17)$$

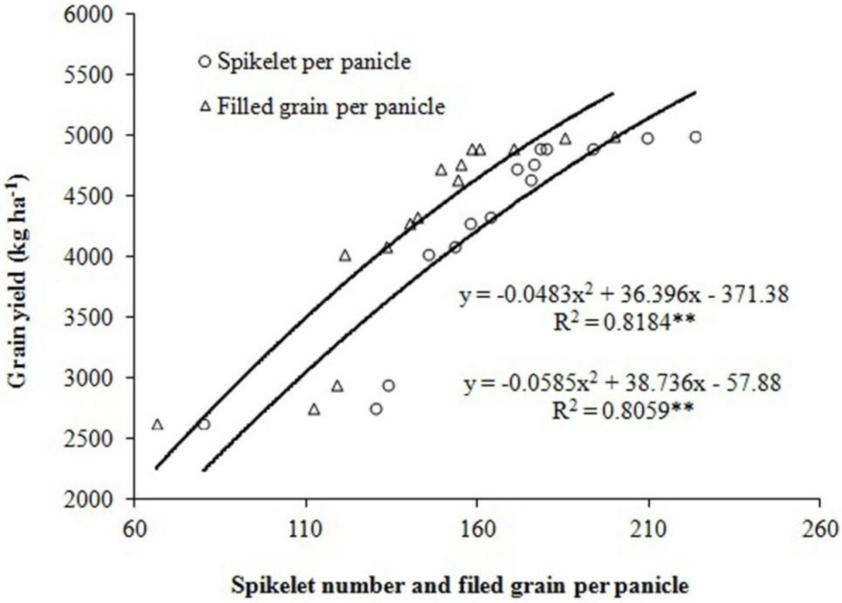

Figure 8. Relationship between spikelet, filled grain per panicle and grain yield, T. Aman 2010, BRRI, Gazipur.

A negative linear association between % unfilled grain and grain yield of T. Aman rice was observed while a positive quadratic association was observed between 1000 grain weight and grain yield (Figure 9). The fitted regression models could be described by the equation 18 and 19, respectively.

$$y = -244.05x + 7345.8, \qquad R^2 = 0.3411^{*} \quad (18)$$
$$y = 369.68x^2 - 13019x + 117570 \qquad R^2 = 0.4851^{**} \quad (19)$$

The % unfilled grain and 1000 grain weight accounted for 34.11 and 48.51% of the variability of rice grain yield, respectively.

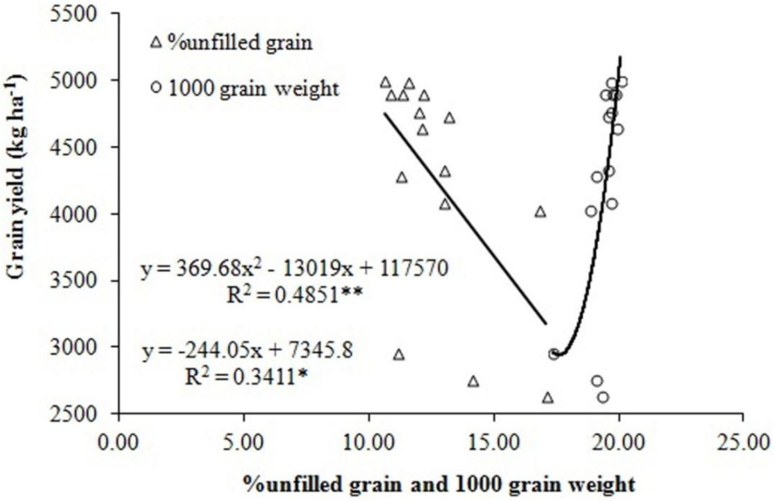

Figure 9. Relationship between unfilled grain, 1000-grain weight and grain yield, T. Aman 2010, BRRI, Gazipur.

The GHI was significantly and quadratically associated with grain yield (Figure 10). The equation was as follows. The GHI accounted 67.09% variability of T. Aman rice grain yield.

$$y = -147.5148x^2 + 12330.3087x - 252997.0289, \quad R^2 = 0.6709^{**} \qquad (20)$$

Shoot dry weight at PI stage and at maturity had also significant and positive association with grain yield (Figure 11 and 12). The equations 21 and 22 explained the relationships.

$$y = -0.0007x^2 + 7.3945x - 14702, \quad R^2 = 0.8400^{**} \qquad (21)$$
$$y = 0.4479x - 402.56, \qquad R^2 = 0.9866^{**} \qquad (22)$$

The increase in grain yield with increasing of dry matter yield at maturity was linear in fashion whereas with of the dry matter yield at PI stage was quadratic. Shoot dry matter at PI and harvest stages accounted for 84.00 and 98.66% of the variability in rice grain yield. Hence, increasing dry weight can increase grain yield of lowland rice up to some extent.

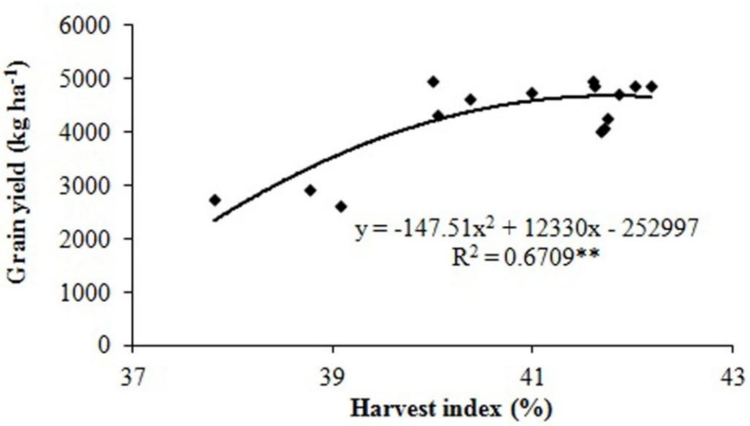

Figure 10. Relationship between Grain harvest index and grain yield, T. Aman 2010, BRRI Gazipur.

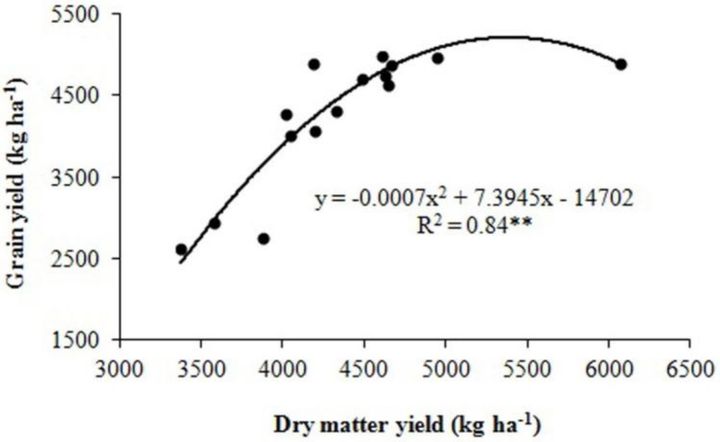

Figure 11. Relationship between dry matter at PI stage and grain yield, T. Aman 2010, BRRI Gazipur.

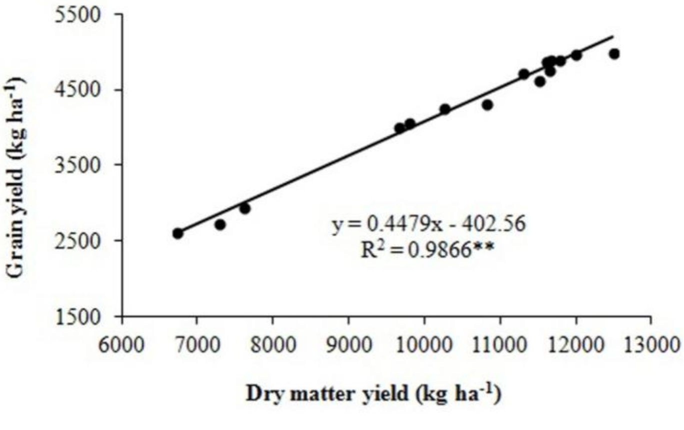

Figure 12. Relationship between dry matter at maturity and grain yield, T. Aman 2010, BRRI Gazipur.

DISCUSSION

Increase in plant height may be due to the increasing of K and N uptake with increasing of applied K. The 1000-grain weight is one of the most important components of the yield. Heavier the grain, the greater will be the yield. Potassium has important role in starch synthesis and grain development (Mengal 1982) thus its adequate supply showed a positive effect in producing heavier rice grain (Niazi *et al.*, 1992).

Dry matter production is the ultimate goal of application of any inputs in crop because it is directly related to the yield. From the regression curve it was observed that about 19 kg dry matters were produced by one kg of applied K at PI stage. This finding suggests the application of adequate K fertilizer for producing more dry matter at vegetative phase because it is directly related to rice yield. Nitrogen is one of the major elements required for plant growth like plant height, shoot dry matter (Fageria and Barbosa Filho, 2001; Fageria and Baligar, 2005; Fageria *et al.* 2003). So, nitrogen deficiency retarded crop plant growth. As the application of inorganic K fertilizer increased the photosynthetic capacity and translocation of photo-assimilate availability of NPK for plant which rendered the maximum dry matter production at PI stage that enhanced the growth, plant height and tillering of rice plants.

The higher yield with higher K dose might be due to the contribution of K, which positively influences all the yield contributing characters of rice plants. Saha *et al.* (2011) reported that 50 kg K ha^{-1} should be applied in clay-loam soil of BRRI farm Gazipur to obtain maximum rice yield in both T. Aman and Boro seasons while Ahsan *et al.* (1997) found response up to 90 kg K ha^{-1} at the same farm. However, Naher *et al.* (2011) reported that potassium fertilizer responded up to 80 kg K ha^{-1} in the clay-loam soil of BRRI farm Gazipur. Ahsan *et al.* (1997) reported that the K rates that maximized the yield of BR11 variety varied from 78 to 104 kg ha^{-1} and the K rates that maximized the profit varied from 65 to 82 kg ha^{-1} in different years in wet season. They found higher rates for maximum yield compared to this study. This might be due to the yield potential of the variety tested. The yield potentials of BR11 and BRRI dhan49 are 6.6 and 5.5 t ha^{-1}, respectively.

Increased rate of potassium helps to produce large amounts of starch due to K-mediated carbohydrate metabolism. Besides, it helps in efficient translocation of photo-assimilates to the developing sinks/spikelets (Beringer 1978) and enables the plants to utilize fully applied N and P fertilizers. Thus, K helps the rice grain and straw to gain large volume and heavier weight.

As the proportion of total plant weight that is economic yield, GHI quantifies the capacity of a genotype to allocate resources, including K, to the harvested organs. A high GHI is fundamental to efficient utilization of all resources taken up by the plant. Higher GHI might be due to better grain yield with corresponding biological yield. The higher doses of K fertilizer increased straw yield more than the grain yield of T. Aman rice.

Snyder and Carlson (1984) reviewed GHI of rice and noted variations from 0.23 to 0.50. However, Kiniry *et al.* (2001) reported that rice GHI varied greatly among cultivars, locations, seasons, and ecosystems, and ranged from 0.35 to 0.62. Fageria and Barbosa Filho (2001) reported GHI values of lowland rice genotypes varied from 0.33 to 0.44. The limit to which GHI can be increased is considered to be about 0.60 (Austin *et al.*, 1980).

In recent years, the utilization of not only grain, but also rice residue such as straw as an energy resource has been seriously considered for alternative energy production systems that reduce CO_2 production (Matsumura *et al.* 2005). Therefore, increasing biomass productivity of rice is a critical research target. An increase in grain yield can be achieved by increasing the harvest index, which indicates the partitioning of assimilation products to grain, and/or total biomass production (Evans 1993, Richards 2000). Improvements in grain yield by breeding during the last half century have been achieved mainly through improving the harvest index (Matsumura *et al.* 2005). However, further increases in grain yield require improvements in biomass production (Kondo 2001).

Yoshida (1981) reported that the percentage of ripened spikelets decreased when the number of spikelets per unit area increased. Hence, there appears to be an optimum number of spikelets for maximum grain yield under certain conditions and attempts to increase spikelet number per unit area will not result in increased grain yield. Under most conditions, the 1000 grain weight of field crops is a very stable varietals character (Yoshida ,1981).

Fageria and Baligar (2001) and Fageria and Barbosa Filho (2001) reported that grain yield of lowland rice increased significantly and quadratically with increasing shoot dry weight. Hasegawa (2003) reported that higher yields of rice cultivars were associated with higher dry matter. Peng *et al.* (2000) also reported that the increasing trend in yield of rice cultivars released by the IRRI before 1980 was mainly due to the improvement in GHI, while an increase in total biomass was associated with yield trends for cultivars released after 1980. These authors also suggested that further increases in rice yield potential would likely occur through increasing biomass production rather than increasing GHI.

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