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Original Article

Rate and application methods of potassium in light soil for irrigated spring wheat

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Abstract

A field experiment was conducted at the Wheat Research Sub-Station of the Bangladesh Agricultural Research Institute, Debigonj-Panchagarh, Bangladesh in two wheat-growing seasons to verify the existing potassium (K) rate and to assess the effect of the K application method on wheat cultivation. Eight levels of K were applied: 24 kg K_2O ha^{-1} (all as basal), 24 kg K_2O ha^{-1} (1/2 as basal and 1/2 at 18 days after sowing (DAS)), 48 kg K_2O ha^{-1} (all as basal), 48 kg K_2O ha^{-1} (1/2 as basal and 1/2 at 18 DAS), 72 kg K_2O ha^{-1} (all as basal), 72 kg K_2O ha^{-1} (1/2 as basal and 1/2 at 18 DAS), 96 kg K_2O ha^{-1} (all as basal), 96 kg K_2O ha^{-1} (1/2 as basal and 1/2 at 18 DAS). Grain and biomass yields increased gradually as K_2O level increased up to 72 kg ha^{-1} for both the basal and split application. Yield did not increase even when the dose of K_2O was increased from 72 to 96 kg K_2O ha^{-1}. A similar trend was observed in the number of spikes m^{-2}, number of grains $spike^{-1}$ and 1000-grain weight. Therefore, 72 kg K_2O ha^{-1} is recommended for wheat production in light soil.

Keywords: wheat, K, rate, application methods, soil

1. Introduction

Potassium (K) is the third most important macro-nutrient required for plant growth, after nitrogen (N) and phosphorus (P), and is one of the principle plant nutrients underpinning crop yield production and quality determination. Potassium is commonly found in plants at levels above all other macronutrients except carbon, oxygen, hydrogen and occasionally nitrogen (Soil Quality Organization, SQO, 2015). As K is involved in many physiological processes, its impact on water relations, photosynthesis, assimilate transport, and enzyme activation can have direct consequences on crop productivity (Pettigrew, 2008) by regulating the opening and closing of stomata and therefore regulating moisture loss from the plant. For this reason, K is colloquially known as “poor-man’s irrigation” because it assists crops to achieve yields more effectively (SQO, 2015). The requirement for K varies from plant to plant and from species to species. For example, wheat requires K for optimal growth and development while adequate K results in superior quality of the whole plant due to improved photosynthetic efficiency, increased resistance to some diseases, greater water use efficiency, and helps to maintain a normal balance between carbohydrates and proteins. Sufficient K results in stronger wheat straw and assists in grain filling (Agri-News, 2012).

In the absence of a satisfactory supply of potash, plants will grow poorly and be stunted, especially in dry seasons. Physiological stress will be more damaging if potash nutrition is limiting, and frost damage will be more severe, waterlogged areas will take longer to recover and plants will wilt earlier and remain flaccid for longer under drought conditions. Crops will be more susceptible to diseases and pests, espe-

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cially where N and potash availability are imbalanced, which will result in weaker growth (PDA, 2012). A high concentration of soluble N compounds and simple carbohydrates provide a readily available food source that is attractive for pathogens. Thinner cell walls with less mechanical resistance to predators may also result from a shortage of K. A review of over 1,000 cereal trials found that where potash levels were low and out of balance with N supply, the application of potash reduced disease and bacterial infections in over 70% of cases (PDA, 2012).

Cereals require a balance between N and potash to obtain a full yield response to applied N. Careful optimization of N is a waste of time if potash supplies are not adequate. If potash supply is limiting then the uptake and utilization of N will be restricted. If soluble forms of N remain in the soil and are not taken up there is an increased risk of leaching when through-drainage occurs (PDA, 2012). The ready availability of both nutrients at a crop's peak helps the uptake of large N and K requirements. During rapid vegetative growth, the rapid uptake of N as negatively charged nitrate ions (NO_3^-) is normally balanced by a similar uptake of positively charged potash ions (K^+) which maintains the electrical neutrality of the plant. Adequate potash is thus clearly important in the production of quality wheat as it assists the conversion of N to protein (PDA, 2012).

The Soil Quality Organization in Australia noticed that sandy soils in high rainfall areas are prone to K deficiency (SQO, 2015). Soils are being exhausted in Bangladesh due to high cropping intensity and the introduction of high-yielding varieties and new technologies to meet the demand of an increasing population (Noor *et al.*, 2014). Earlier findings indicated that the fertility status of most Bangladeshi soils has deteriorated (Ali *et al.*, 1997; Islam, 2008), which is responsible for the stagnation and in some cases, decline, of crop yields. The use of chemical fertilizers such as N, P, K and sulfur (S) has been increasing steadily, but these have not been applied in a balanced way, which led to a depletion of constituent nutrients. Previous research results indicated that annual rates of depletion of N, P, K and S in areas under intensive cultivation ranged between 180 to 250 kg ha^{-1} yr^{-1} (Noor *et al.*, 2014). On the other hand, K is the third major plant nutrient following N and P. Analysis of nutrient use ratio shows that K use is low, i.e., deficient in most soils in Bangladesh (Noor *et al.*, 1998). Soil in the north-western part of Bangladesh is deficient in K due to increasing cropping intensity, excessive rice cultivation (three times a year on the same land), use of high-yielding varieties and greater use of N and P fertilizers to meet the demand of an increasing population (Saha *et al.*, 2010). As high-yielding varieties are introduced under an intensive cropping system in Bangladesh, it is assumed that current K recommendations are insufficient for growing wheat with optimum yield (Saha *et al.*, 2010), and because soil is light, K may leach from the soil during wet cultivation cropping. On the other hand, in Bangladesh, K is recommended for wheat only when used as basal with other fertilizers, during final land preparation (WRC, 2009). However, other studies (Pettigrew, 2008; Nadim *et al.*, 2012; PDA, 2012) indicated that a split application of K could enhance wheat yield. Thus, it is essential to verify the present recommendation and K application method for wheat cultivation in Bangladesh. Therefore, the present experiment was undertaken to assess the optimum rate and application method of K for wheat cultivation.

2. Materials and Methods

This study was conducted at the experimental field of the Wheat Research Sub-Station, Debigonj-Panchagarh, Bangladesh, in two wheat-growing seasons (November to April, 2007-2008 and 2008-2009). The area falls under Agro Ecological Zone 3, the Tista Meander Flood Plain of Bangladesh (FAO/UNDP, 1988).

Treatments were as follows: T_1 (control) = 24 kg K_2O ha^{-1} (all as basal), T_2 = 24 kg K_2O ha^{-1} (½ as basal and ½ at 18 days after sowing (DAS)), T_3 = 48 kg K_2O ha^{-1} (all as basal), T_4 = 48 kg K_2O ha^{-1} (½ as basal and ½ at 18 DAS), T_5 = 72 kg K_2O ha^{-1} (all as basal), T_6 = 72 kg K_2O ha^{-1} (½ as basal and ½ at 18 DAS), T_7 = 96 kg K_2O ha^{-1} (all as basal), T_8 = 96 kg K_2O ha^{-1} (½ as basal and ½ at 18 DAS). The experiment was conducted in a randomized complete block design with three replications.

An existing elite wheat variety 'Prodip' from the Wheat Research Center (WRC), Dinajpur, Bangladesh, was used as the experimental material. Before sowing, seeds were treated with Provax-200 WP, a seed-treated fungicide containing Carboxin and Thiram. Research conducted at the WRC (2009) indicated that Provax-200 WP is a perfect match for controlling fungi in Bangladesh soil, for achieving excellent seed germination and for protecting wheat cultivars from fungal attacks during the seedling stage. This fungicide is marketed by Hossain Enterprise CC Bangladesh Ltd., an agrochemical company engaged in crop protection and seed treatment, in association with Chemtura Corp., U.S.A. Seeds were sown at 120 kg ha^{-1}. Unit plot size was 1.6 × 4 m {4 m long, 8 rows and a row-to-row distance of 20 cm (i.e., 9.6 g seeds row^{-1})}.

Fertilizer was applied at doses recommended by the WRC with 100-62-20-1 kg ha^{-1} of N, P_2O_5, S, and B (boron). K_2O was applied according to treatments T_1 to T_8. Two-thirds of N and a full amount of the other fertilizers were applied as a basal amount during final land preparation. The remaining N fertilizer was applied immediately after the first irrigation (18 DAS). Second and third irrigations were applied at booting (45 DAS) and grain-filling (70 DAS) stages.

The crop was harvested plot-wise at full maturity on a treatment-by-treatment basis. Sample plants were harvested separately from an area of 3×1.2 m (i.e., 3 m long with 6 middle rows) to avoid border effects. The harvested sample crop of each plot was bundled separately, tagged and taken to a threshing floor. The bundles were thoroughly dried under bright sunshine until fully dried, then weighed and threshed. Data on plant height (PH), number of spikes m^{-2} (NSPM), number of grains spike^{-1} (NGS), 1000 grain weight (1000-GW), biomass yield (BY), and grain yield (GY) were measured. To obtain the actual 1000-GW and final GY, grain weight was adjusted to 12% moisture with the following equation (Hellevang, 1995):

$$Y(M_2) = \frac{100 - M_1}{100 - M_2} \times Y(M_1)$$

where Y (M_2) is the weight of grain at an expected moisture percentage (generally 12% for wheat), Y (M_1) is the weight of grain at the present moisture percentage, M_1 is the present moisture percentage, and M_2 is the expected moisture percentage.

The surface soil (0-15 cm) was sampled at the start of the experiment from the experimental site and individual plots after wheat harvest for analysis (Figure 1). Soil K was analyzed by a modified Hunter's method (Kendall, 1911) in the soil laboratory of the WRC. Average weather data for both wheat-growing seasons was recorded from the meteorological station of the Breeders Seed Production Centre, BARI (Bangladesh Agricultural Research Institute), Debigonj-Panchagarh, Bangladesh (Table 1). The data was analyzed using MSTAT-C (Russell, 1994). Treatment means were compared for significance by Duncan's multiple range test (DMRT) at P = 0.05.

3. Results and Discussion

3.1 Weather condition at experimental period

Wheat is a climate-sensitive crop, especially to temperature (Almeselmani *et al*., 2015). Temperature below or above normal levels affects the growth and development, and finally grain yield, of wheat. Optimum temperature for germination, vegetative growth and grain-filling of spring wheat is 12-25 °C (Hakim *et al.*, 2012; Hossain and Teixeira da Silva, 2012; Hossain *et al.*, 2012a, b). Two years' average weather data of the wheat-growing seasons indicate that climatic factors were favorable for proper growth and development of experimental wheat (Table 1).

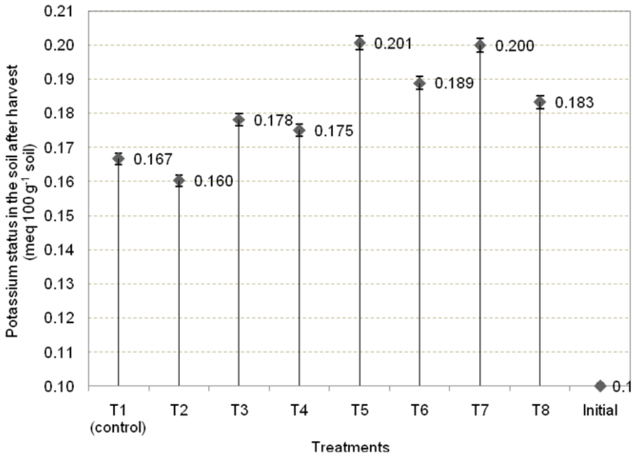

Figure 1. Soil potassium content before experiment (initial) and after wheat harvest (after two years' experimentation). T_1 (control) = 24 kg K ha^{-1} (all as basal), T_2 = 24 kg K_2O ha^{-1} (½ as basal and ½ at 18 days after sowing (DAS)), T_3 = 48 kg K_2O ha^{-1} (all as basal), T_4 = 48 kg K_2O ha^{-1} (½ as basal and ½ at 18 DAS), T_5 = 72 kg K_2O ha^{-1} (all as basal), T_6 = 72 kg K_2O ha^{-1} (½ as basal and ½ at 18 DAS), T_7 = 96 kg K_2O ha^{-1} (all as basal), T_8 = 96 kg K_2O ha^{-1} (½ as basal and ½ at 18 DAS).

Table 1. Average weather data for two wheat-growing seasons (November to April, 2007 to 2008 and 2008 to 2009) (Source: Meteorological station of Breeders Seed Production Centre, BARI, Debigonj-Panchagarh, Bangladesh).

Month		Sunshine (hr)	Humidity (%)	Temp. (°C)		Evaporation (mm)	Wind-run 2 mt-ht (km/h)	Total rainfall (mm)
				Min.	Max.			
November	1-15	8.7	93.6	18.9	31	3.0	18.7	3
	16-30	8.5	90.7	15.2	29.2	3.1	25.4	-
December	1 -15	6.4	92.3	12.5	26.5	2.0	16.9	-
	16-31	4.4	91.6	10.1	24.6	1.5	13.2	-
January	1-15	5.6	89.0	10.4	25.6	1.4	15.4	-
	16-31	2.3	89.3	11.7	22.1	1.9	40.7	41
February	1-15	5.6	89.9	10.0	22.9	2.0	19.9	1
	16-29	7.0	89.1	12.2	27.7	2.4	23.1	4
March	1-15	3.3	88	16.7	29.5	2.7	31.8	24.5
	16-31	2.9	88.3	12.3	31.4	4.6	40.9	0.5
April	1-15	7.4	90.1	11.2	32.4	4.7	42.8	19

3.2 Initial and post-harvest K status in the soil

Mahmud *et al.* (2009) noticed that the nutrient status of soils of the experimental sites was 17, 9, 3, and 6 $\mu g\ ml^{-1}$ of NH_4-N, P, Zn, and S, respectively, 0.10, 1.9, and 0.65 meq 100 g^{-1} of K, Ca, and Mg, respectively, organic matter was 0.73%, pH of the soil was 6.4, while soil type of the experimental site was sandy loam; however, K, Ca, and Mg were below the critical level (critical level of K, Ca, and Mg are 0.12, 2.0 and 0.5 meq 100 g^{-1}).

After wheat was harvested, the K levels of individual plots were analyzed (Figure 1). Data following soil analysis indicated that K was higher in the soil when applied as basal. It was higher in high-dose plots and lower in low-dose plots (Figure 1). On the other hand, wheat yield and yield components also performed better in plots to which basal levels were applied, indicating that split application of K_2O was not effective for wheat production in the light soil of northern Bangladesh. This is because the split application of K_2O (18 DAS) forms an insoluble compound with the first irrigation (18-21 DAS), which is an unavailable form for growing wheat.

The International Potash Institute (IPI) (2012) stated that many water sources have high contents of Ca, Mg and bicarbonates (hard waters) resulting in pH values between 7.2 and 8.5. When K-fertilizers are added, precipitates can form in the soil. The addition of K_2SO_4 to hard waters may cause the precipitation of $CaSO_4$ (Bar-Yosef, 1999), while the addition of KH_2PO_4 may form precipitates of Ca and Mg phosphates. KCl and KNO_3 are the preferred forms of K because they do not pose any problems of clogging or precipitation, even with hard waters (IPI, 2012).

3.3 Yield and yield-related components

3.3.1 Plant height

Plant height (PH) is an important component of straw yield and may also affect grain yield. The growth and development of a plant depends on the crop species being grown, the amount of nutrients in the native soil, the amount of applied fertilizer, the nutrient availability in the soil, the environmental conditions during the growing season and the management practices employed (Mullins and Burmester, 1998; Mengel and Kirkby, 2004). In our research, no significant difference was found in PH for all treatments. Highest PH was found for 72 kg $K_2O\ ha^{-1}$ (applied as basal) and 96 kg $K_2O\ ha^{-1}$ (½ as basal + ½ at 18 DAS) K_2O-treated plots (Figure 2). Tariq *et al.* (2001), Jahan *et al.* (2009) and Saha *et al.* (2010) also found a non-significant effect of K in lentil and wheat PH in the northern part of Bangladesh. Our results and these previous results indicate that PH is not influenced by the dose and split application of K_2O.

3.3.2 Number of spikes per area

Crop yield mainly depends upon many yield-contributing components. Among them, the number of spikes per area (NSPM) is very important because the higher the NSPM, the higher the final crop yield. Different potash levels and their interaction with methods of application significantly affected total NSPM. The highest NSPM was observed 72 kg K_2O applied as basal, which was similar to 96 kg K_2O applied as basal and split (½ as basal + ½ at 18 DAS) (Figure 3). Relative to the control (24 kg as basal), the percentage increase of NSPM was equal to that of 72 kg K_2O applied as basal, followed by 96 kg K_2O applied as basal and split (½ as basal + ½ at 18 DAS). Tahir *et al.* (2008) also reported that NSPM was higher when crops were fertilized with K relative to the control.

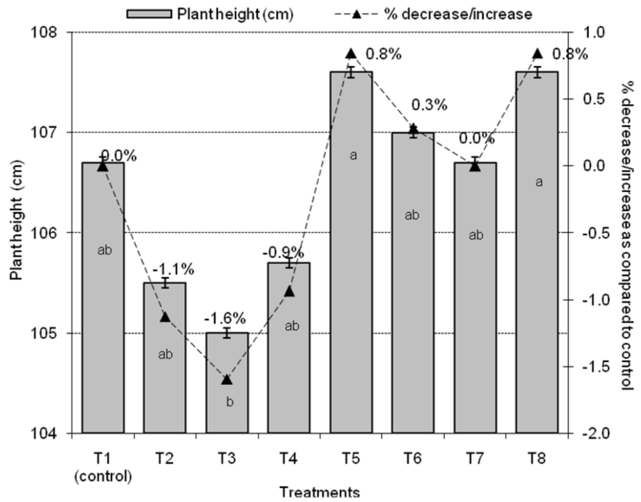

Figure 2. Plant height of wheat as affected by K_2O rate and application method. Bars with the same letter do not differ significantly at 5% level by DMRT. Treatment details are presented in Figure 1.

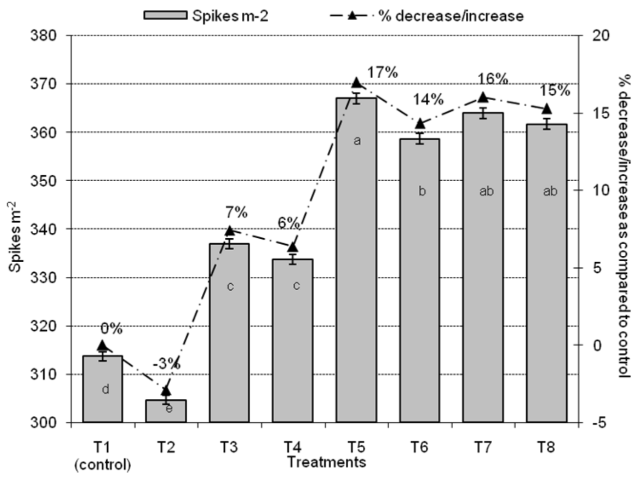

Figure 3. Number of spikes m^{-2} of wheat as affected by K_2O rate and application method. Bars with the same letter do not differ significantly at 5% level by DMRT. Treatment details are presented in Figure 1.

3.3.3 Number of grains per spike

The number of grains per spike (NGS) is an important yield-contributing parameter and has a direct effect on the final grain yield of wheat. All K_2O levels produced significantly higher NGS than the control (Figure 4). Maximum NGS was observed when the crop was fertilized with 72 kg K_2O ha^{-1} as basal (32% increase), followed by 96 kg K_2O ha^{-1} as basal (29% increase). Minimum NGS was found in the control plot (24 kg K_2O applied as basal and splits), followed by 48 kg K_2O applied as basal and splits (14-19% increase over the control). Gwal *et al.* (1999), Maqsood *et al.* (1999) and Tahir *et al.* (2008) also stated that a higher dose of K applied as basal gave highest NGS.

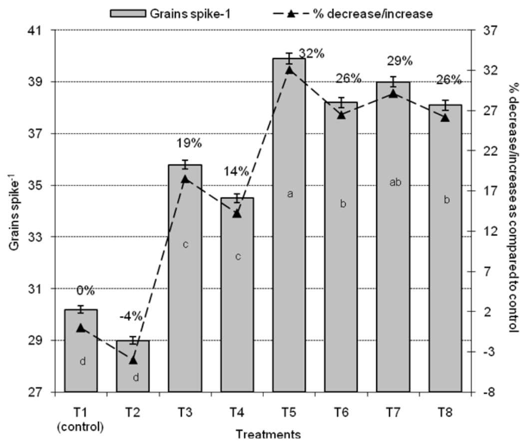

Figure 4. Number of grains spike^{-1} of wheat as affected by K_2O rate and application method. Bars with the same letter do not differ significantly at 5% level by DMRT. Treatment details are presented in Figure 1.

3.3.4 1,000-grain weight

The application of potash in different proportions with recommended doses of N and P increased 1000 grain weight (1,000-GW) more than the control (Figure 5). Maximum and statistically similar 1000-GW was recorded when the crop was fertilized with 72 and 96 kg K_2O ha^{-1} (both as basal and as splits) (11% increase over the control) and minimum 1000-GW was recorded in the control plot, statistically followed by 48 kg K_2O applied as basal and splits (5-6% greater than the control) (Figure 5). Grains produced in the control treatment were light in weight due to low K uptake from the soil, reducing thus the translocation of metabolites which is important for grain filling and development. K is a co-factor for several enzymes and its effect on starch synthesis is well established. Therefore, the availability of K can have a profound effect on grain development. Sultan (1995), Dilshad *et al.* (2000), Ijaz (2004) and Tahir *et al.* (2008) reported that the 1000-GW of wheat increased by adding K fertilizer to crop plants.

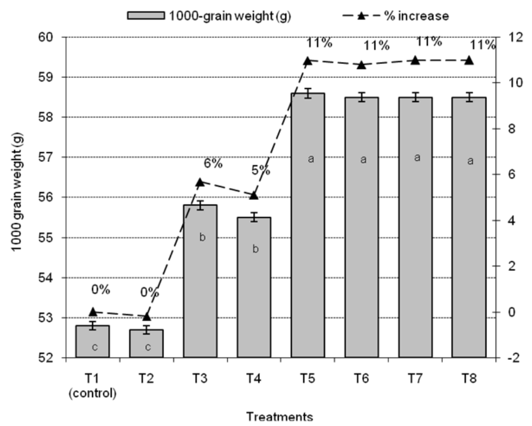

Figure 5. 1000-grain weight (g) of wheat as affected by K_2O rate and application method. Bars with the same letter do not differ significantly at 5% level by DMRT. Treatment details are presented in Figure 1.

3.3.5 Biomass yield

There was no effect by the split application of K_2O on biomass yield (BY), although it was significantly influenced by the rate of application (Figure 6). The highest BY was obtained with 72 kg K_2O ha^{-1} as basal which was similar to 72 kg K_2O ha^{-1} as split and to 96 kg K_2O ha^{-1} as basal and split, and was significantly higher than other treatments (14% increase over the control). Minimum BY production was observed in the low rate K_2O-treated plot, resulting in an overall reduction in the amount of photosynthetic assimilates available for growth (Pettigrew, 2008). The production of less photosynthetic assimilates and reduced assimilate transport out of the leaves to the developing grain greatly contributes to the negative consequences that K deficiency has on yield and quality production (Pettigrew, 2008).

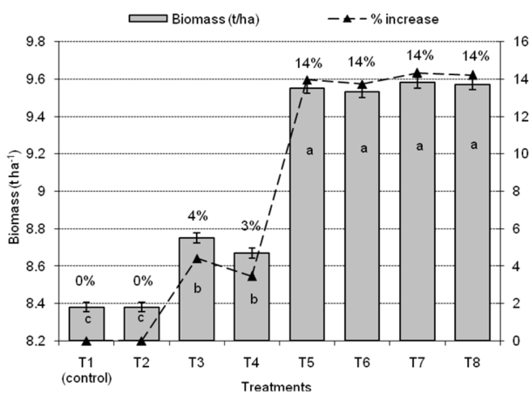

Figure 6. Biomass yield (t ha^{-1}) of wheat as affected by K_2O rate and application method. Bars with the same letter do not differ significantly at 5% level by DMRT. Treatment details are presented in Figure 1.

3.3.6 Grain yield

Potassium is one of the principle plant nutrients determining crop yield production and quality. While involved in many physiological processes, K's impact on water relations, photosynthesis, assimilate transport and enzyme activation can have direct consequences on crop productivity (Oosterhuis *et al.*, 2014). K-deficiency can lead to a reduction in both the number of leaves produced and the size of individual leaves. Coupling this reduced amount of photosynthetic source material with a reduction in the photosynthetic rate per unit leaf area, and the result is an overall reduction in the amount of photosynthetic assimilates available for growth. The production of less photosynthetic assimilates and reduced assimilate transport out of the leaves to the developing fruit greatly contributes to the negative consequences that deficiencies of potassium have on yield and quality production (Pettigrew, 2008). This mechanism also most likely took place in wheat where grain yield (GY) responded strongly to the application of K (Figure 7). GY increased as the level of K_2O application increased up to 72 kg K_2O ha^{-1}, which was statistically similar to 72 kg K_2O ha^{-1}. The peak in GY at 72 kg K_2O ha^{-1} as basal resulted in a 52% increase over the control. This data indicates that the cumulative effect of yield-contributing characters, such as NSPM, NGS, and 1000-GW contributed positively to higher GY obtained when K_2O was applied at 72 kg ha^{-1}. In the control, the growth and development of plants were hampered due to an imbalance uptake of essential elements which resulted in poor performance of yield attributes and ultimately gave the lowest GY. Alam *et al.* (2009), who conducted a two-year field experiment in northern Bangladesh, also stated that yield-contributing characters and yield showed a significant increase in grain, straw and total biomass yield when a higher dose of K was applied.

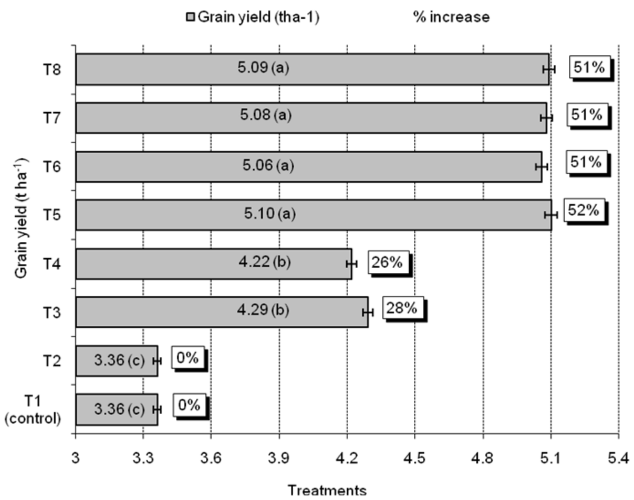

Figure 7. Grain yield (t ha^{-1}) of wheat as affected by K_2O rate and application method. Bars with the same letter do not differ significantly at 5% level by DMRT. Figure percentage in the bars indicates % increase relative to the control. Treatment details are presented in Figure 1.

4. Conclusions

GY and BY increased gradually increased as K_2O level increased up to 72 kg ha^{-1} for both the basal and split application. Yield did not increase statistically after the addition of 96 kg K_2O ha^{-1} much more than 72 kg K_2O ha^{-1}. A similar trend was observed for NSPM, NGS, and 1000-GW. Therefore, 72 kg K_2O ha^{-1} is recommended for wheat production in K-deficient light soil.

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