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Split application of varying potassium (K) rates influence wheat yield and K use efficiency

Sufia Khatun[1], Farhana Zaman[1], Md Mosaraf Hossain[2], Mohammad Joyel Sarker[3], Ahmed Khairul Hasan* [1]

[1]Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[2]Mouza and Plot Based National Digital Land Zoning Project, Ministry of Land, Bhumi Bhaban (12th floor), 98 Shaheed Tajuddin Ahmed Sarani Tejgaon, Dhaka 1208, Bangladesh
[3]Bangladesh Institute of Nuclear Agriculture, Cumilla Sub-Station, Cumilla, Bangladesh

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Md Harun Rashid
mhrashid@bau.edu.bd

**Corresponding Author*
Ahmed Khairul Hasan
akhasan@bau.edu.bd

ABSTRACT

Potassium (K) application during land preparation doesn't meet the crop requirement as huge amount of K is lost. Moreover, dose also should be optimized considering land, soil and variety. Therefore, a field experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, to explore the influence of different management levels of K on yield and potassium use efficiency of wheat. Two wheat varieties (BARI Gom-27 and BARI Gom-33) and nine potassium (K) management levels [K0 = 0 kg K ha^{-1}, K1 = 40 kg K ha^{-1} (full as basal), K2 =40 kg K ha^{-1} (half as basal and half at active tillering stage), K3 = 60 kg K ha^{-1} (full as basal), K4 = 60 kg K ha^{-1} (half as basal and half at active tillering stage), K5 = 80 kg K ha^{-1} (full as basal), K6 = 80 kg K ha^{-1} (half as basal and half at active tillering stage), K7 =100 kg K ha^{-1} (full as basal), K8 = 100 kg K ha^{-1} (half as basal and half at active tillering stage)] were used as treatments. The results of potassium management levels revealed that yield and yield components of wheat except straw yield were increased with the split application of potassium (K) (half as basal + half at active tillering stage) at 80 kg ha^{-1} and decreased with no potassium (K) application. The highest grain yield (4.37 t ha^{-1}) was obtained from 80 kg K ha^{-1} applied as split which was 69.37% higher than the control. The potassium agronomic efficiency (5.50%) and apparent potassium recovery efficiency (29.17 kg kg^{-1}) were highest in the treatment application of potassium at 40 kg ha^{-1} (half as basal and half at active tillering stage) grown with BARI Gom-33. In split application and 80 kg K ha^{-1} condition BARI Gom-33 gave the highest grain yield (4.77 t ha^{-1}). Therefore, it may be concluded that the application of 80 kg K ha^{-1} as split (half as basal and half at active tillering stage) may be followed to achieve higher yield in wheat cultivation.

Keywords: Split application, agronomic efficiency, potassium, K recovery efficiency, wheat

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1 Introduction

Wheat (*Triticum aestivum* L.) is one of the most strategic crops in the world and ranks first in terms of nutritional importance, as it is an essential provider of essential amino acids, minerals and vitamins, etc (Johansson et al., 2013; Ma et al., 2020). In Bangladesh it ranks as the third cereal crop next to rice and maize in terms of acreage and production (BBS, 2022). Earlier findings indicated that the fertility status of most Bangladeshi soils has deteriorated (Ali et al., 1997;

Khan et al., 2005; Islam, 2008; Rashid et al., 2008), which is responsible for the stagnation and in some cases, decline, of crop yields.

Potassium (K) is the third most important macronutrient required for plant growth, after nitrogen and phosphorus and one of the principle plant nutrients underpinning crop yield production and quality determination (SQO, 2015). In wheat, there is a decrease in seed size due to insufficient K and this affects the grain filling duration (Ashraf et al., 2011; Lv et al., 2017; Ali et al., 2022). K is referred to be 'poor man's irrigation' because it assists crops achieve yield more effectively (SQO, 2015). Sufficient K makes wheat straw stronger and assists grain filling. Cereals require a balance of N and K to obtain a full yield response to applied N. Adequate potassium is thus clearly important in the production of quality wheat as it assists the conversion of N to protein (PDA, 2012).

Proper potassium management practices especially split application of potassium at optimum dose favourably influences the yield and yield attributing characteristics of wheat than single basal application (Yang et al., 1997; Chaudhary and Roy, 1992) to medium to low K status as evidenced by soil testing. The lower K in soil also results in the limiting of other essential nutrients for a higher crop yield. Seldom do workers report on the timings of K application on a yield of wheat and other crop plants. So, to reduce the fixation of K and to increase its availability, a split application K during the growth period has proven to be beneficial by simultaneously lowering the loss of K by leaching and by raising the use efficiency of the K fertilizers applied (Romheld and Kirkby, 2010).

Split application of K significantly increased the uptake efficiency, productive efficiency of K also increases the grain yield and its protein and wet gluten contents in wheat grains to a greater extent than the basal application of K alone (Lu et al., 2014). Split application of potassium increases higher number of tiller m^{-2}, dry-matter accumulation, leaf area index, SPAD reading, average number of spikes m^{-2}, number of grains spike^{-1} and 1000 grain weight over the treatments application of potassium as 100% basal dose (Akhter et al., 2017).

In the absence of a satisfactory K supply, plants will grow poorly and be stunted, physiological stress will be more damaging, waterlogged areas will take longer to recover under drought conditions, uptake and utilization of nutrient will be restricted (PDA, 2012). In Bangladesh, K is recommended for wheat only when used as basal with other fertilizers, during final land preparation (WRC, 2009). However a split application of potassium could enhance wheat yield (Pettigrew, 2008; Nadim et al., 2012; PDA, 2012). Thus, it is essential to verify the present recommendation and K application method for wheat cultivation in Bangladesh. The present experiment was therefore undertaken to determine the effect of rate and split application of K on yield of wheat and to elucidate the K use efficiency of wheat under varying dose and timing of K application.

2 Materials and Methods

2.1 Experimental site and duration

The experiment was implemented at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh during the period from November 2019 to April 2020. The experimental field was located at 24°43′11.1″N, 90°25′42.2″E at an elevation of 18 m above the sea level belonging to non-calcareous dark gray floodplain soil under Old Brahmaputra Floodplain (AEZ-9). The experimental field was a medium high land with silty clay loam soil texture having pH value of 6.5. The soil of the experimental field was low in organic matter content (1.29) and the fertility level of the soil was low (0.1% total N, 26 ppm available P and 0.14 me exchangeable K). The climate of the locality is subtropical in nature and is characterized by high temperature and heavy rainfall.

2.2 Experimental treatments and design

The experiment comprised two factors namely, variety and potassium (K) management. Two wheat varieties included (i) BARI Gom-27 and (ii) BARI Gom-33. While nine potassium (K) management levels were (i) 0 kg K ha^{-1} (control), (ii) 40 kg K ha^{-1} (full as basal), (iii) 40 kg K ha^{-1} (half as basal and half at active tillering stage), (iv) 60 kg K ha^{-1} (full as basal), (v) 60 kg K ha^{-1} (half as basal and half at active tillering stage), (vi) 80 kg K ha^{-1} (full as basal), (vii) 80 kg K ha^{-1} (half as basal and half at active tillering stage), (viii) 100 kg K ha^{-1} (full as basal) and (ix) 100 kg K ha^{-1} (half as basal and half at active tillering stage). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Altogether there were 54 unit plots in the experiment. The size of each unit plot was 2.0 m × 2.5 m i.e. 5 m^2.

2.3 Crop husbandry

After appropriate land and soil management, seeds were sown on 20 November 2019 and sowing was done at the rate of 120 kg ha^{-1}. The land was uniformly fertilized with 200 kg, 150 kg, 100 kg and 7 kg ha^{-1} of urea, triple super phosphate (TSP), gypsum and boric acid, respectively. Potassium was applied as per the experimental treatments by muriate of postash. Total amount of TSP, gypsum, boric acid and half amount of urea were applied in each plot at the time of final land preparation and the fertilizers were mixed thoroughly with soil by spading. The rest half of urea fertilizer was applied at tillering stage (28 days after sowing). Other cultural operations were done appropriately to raise the crop for higher yield.

2.4 Harvesting and data recording

Crop was harvested at maturity on 20 February, 2020 and recorded different yield and yield contributing characters of wheat. The Harvest index (HI) was calculated with the following formula:

$$\mathrm{HI} = \frac{G_Y}{B_Y} \times 100 \tag{1}$$

where, G_Y = grain yield and B_Y = biological yield.

$$\mathrm{AKRE} = \frac{U_n - U_0}{n} \tag{2}$$

where, AKRE = apparent K recovery efficiency (kg kg^{-1}), U_n stands for nutrient uptake at n rate of fertilizer and U_0 stands for nutrient uptake at control (no fertilizer) and n stands for fertilizer applied.

$$\mathrm{KAE} = \frac{G_n - U_0}{n} \tag{3}$$

where, KAE = K agronomic efficiency (%), G_n and G_0 stand for grain yield of fertilized plots at n rates of fertilizer and grain yield of unfertilized plots, respectively, and n stands for nutrient applied.

2.5 Statistical analysis

The recorded data were compiled and tabulated for statistical analysis. Analysis of variance was done with the help of computer package MSTAT. The mean differences among the treatments were adjudged as per Duncan's Multiple Range Test (Gomez and Gomez, 1984).

3 Results

3.1 Yield contributing characters

3.1.1 Plant height

Application of potassium at 80 kg ha^{-1} caused an increase in plant height by 14.4% to control. There was a significant effect of variety and potassium management (Table 1). The tallest plant (105.80 cm) was achieved from the treatment combination of BARI Gom-33, 80 kg K ha^{-1} and split application of K, half as basal and half at active tillering stage. The shortest plant (88.53 cm) was achieved from the treatment combination of BARI Gom-27 and no K application treatment.

3.1.2 Number of effective tillers hill^{-1}

The highest number of effective tillers hill^{-1} (4.10) was obtained with split application of K at 80 kg K ha^{-1} (half as basal and half at active tillering stage). The lowest number of effective tillers hill^{-1} (2.83) was found in no K application treatment (Table 1). Number of effective tillers hill^{-1} was significantly affected by the interaction of variety and potassium management. The highest effective tillers hill^{-1} (4.50) was achieved from the treatment combination of BARI Gom-33 and split application of K at 80 kg K ha^{-1} (half as basal and half at active tillering stage). The lowest number of total tillers hill^{-1} (2.57) was achieved from the treatment combination of BARI Gom-27 and no K application condition (Table 1).

3.1.3 Number of non-effective tillers hill^{-1}

Potassium management significantly affected the number of non-effective tillers hill^{-1}. The highest number of non-effective tillers (0.47) found at 100 kg K ha^{-1} when applied as basal and same result (0.47) was observed when applied as split (half as basal and half at active tillering stage). The lowest number of non-effective tillers hill^{-1} (0.35) was found when 80 kg K ha^{-1} was applied as both basal and split (Table 1). Variety and potassium management had significant influence on number of non-effective tillers hill^{-1} at 1% level of probability (Table 1). The lowest number of non-effective tillers hill^{-1} (0.23) was achieved from BARI Gom-33 when applied as split at 80 kg K ha^{-1} (half as basal and half at active tillering stage) treatment.

3.1.4 Spike length

The tallest spike (13.79 cm) was obtained from BARI Gom-33 and the shortest one (11.31 cm) was obtained from BARI Gom-27 (Table 1). The highest spike length (13.58 cm) was achieved with the treatment 80 kg K ha^{-1} when applied as split (half as basal and half at active tillering stage), which was statistically identical to basal application of K at 80 kg K ha^{-1}. The lowest spike length (10.97 cm) was achieved from no K application treatment. Split application of K at 80 kg ha^{-1} caused an increase in spike length by 23.79% over the control. The longest spike (14.90 cm) was obtained from the treatment combination of BARI Gom-33 and split application of K at 80 kg K ha^{-1} (half as basal and half at active tillering stage) which was statistically similar with basal application of K at 80 kg ha^{-1}. The shortest spike (9.90 cm) was obtained from the treatment combination of BARI Gom-27 and control (Table 1).

Table 1. Effect of variety, potassium management and their interactions on plant and yield contributing characters of wheat

	PLH (cm)	ETH (no.)	NTH (no.)	SPL (cm)	TSS (no.)	ESS (no.)	NGS (no.)	WTS (g)	HI (%)
Variety (V)									
BARI Gom-27	93.10b	3.31b	0.4	11.31b	14.30b	12.69b	45.76b	37.24b	36.99b
BARI Gom-33	100.09a	3.75a	0.4	13.79a	16.37a	14.86a	47.06a	49.67a	39.04a
SE	3.49	0.22	0	1.24	1.03	0.05	0.3	6.22	1.02
Level of sig.	**	**	NS	**	**	**	**	**	**
K manag. (K)									
K0	88.87d	2.83d	0.43ab	10.97b	13.63c	11.58c	42.62d	38.77e	33.52d
K1	91.57cd	3.17cd	0.35ab	12.10ab	14.58bc	12.60bc	45.50c	40.57d	36.37c
K2	94.35bc	3.33bc	0.37ab	12.17ab	14.75bc	13.12bc	45.92bc	41.42c	36.78c
K3	97.18ab	3.57bc	0.45ab	12.73ab	15.65ab	14.23ab	46.73ab	44.67b	38.78b
K4	98.45ab	3.55bc	0.40ab	12.62ab	15.63ab	14.18ab	47.50a	45.00ab	39.04ab
K5	98.83ab	3.82ab	0.35ab	13.27a	16.27ab	14.88a	47.40a	45.03ab	39.40ab
K6	101.65a	4.10a	0.35ab	13.58a	16.65a	15.32a	47.62a	45.50a	39.98a
K7	98.40ab	3.72ab	0.47a	12.70ab	15.40ab	13.95ab	47.00ab	45.00ab	39.16ab
K8	100.02a	3.68a-c	0.47a	12.80ab	15.45ab	14.05ab	47.42a	45.17ab	39.12ab
SE	1.39	0.12	0.02	0.25	0.3	0.39	0.53	0.84	0.69
Level of sig.	**	**	**	**	**	**	**	**	**
V × K									
V1 × K0	88.53l	2.57g	0.43ab	9.90f	12.03j	9.93h	41.40g	32.10f	32.87i
V1 × K1	88.93kl	3.10fg	0.30c-e	10.50ef	13.50i	11.50g	44.50ef	33.83e	35.18gh
V1 × K2	90.40j	3.20ef	0.30c-e	10.83de	13.83hi	12.07g	45.27e	34.83e	37.14ef
V1 × K3	93.50i	3.40c-f	0.43ab	11.57cd	14.57f-h	13.13f	46.50d	38.83d	37.67ef
V1 × K4	94.53gh	3.33c-f	0.37b-d	11.53cd	14.43gh	12.97f	46.83d	39.00d	38.33de
V1 × K5	95.03g	3.50b-f	0.43ab	11.83c	15.43d-f	14.10c-e	46.80d	38.90d	38.24de
V1 × K6	97.50f	3.70b-f	0.47ab	12.27c	15.80c-e	14.37cd	46.90d	39.50d	38c-e
V1 × K7	94.63gh	3.50b-f	0.47ab	11.63cd	14.50f-h	13.00f	46.83d	39.00d	37.66ef
V1 × K8	94.80g	3.50b-f	0.43ab	11.70cd	14.63f-h	13.13f	46.83d	39.17d	37.34ef
V2 × K0	89.20k	3.10fg	0.43ab	12.03c	15.23e-g	13.23ef	43.83f	45.43c	34.17hj
V2 × K1	94.20h	3.23d-f	0.40a-c	13.70b	15.67de	13.70d-f	46.50d	47.30b	37.55ef
V2 × K2	98.30e	3.47c-f	0.43ab	13.50b	15.67de	14.17c-e	46.57d	48b	36.43fg
V2 × K3	100.87d	3.73b-f	0.47ab	13.90b	16.73a-c	15.33ab	46.97cd	50.50a	39.88bc
V2 × K4	102.37c	3.77b-e	0.43ab	13.70b	16.83ab	15.40ab	48.17ab	51.00a	39b-d
V2 × K5	102.63c	4.13ab	0.27de	14.70a	17.10ab	15.67ab	48a-c	51.17a	40.57ab
V2 × K6	105.80a	4.50a	0.23e	14.90a	17.50a	16.27a	48.33a	51.50a	41.44a
V2 × K7	102.17c	3.93a-c	0.47ab	13.77b	16.3b-d	14.90bc	47b-d	51.00a	40.65ab
V2 × K8	105.23b	3.8b-d	0.50a	13.90b	16.27b-d	14.97bc	48a-c	51.17a	40.90ab
SE	1.31	0.1	0.02	0.35	0.33	0.38	0.41	1.62	0.55
Level of sig.	**	*	**	*	*	*	*	*	*
CV (%)	0.32	9.57	6.85	3.82	3.47	3.86	1.27	1.53	2.43

Means with the same letters or without letters within the same column do not differ significantly; ** = Significant at 1% level of probability, * = Significant at 5% level of probability; PLH = plant height, ETH = number of effective tillers hill^{-1}, NTH = number of non-effective tillers hill^{-1}, SPL = spike length (cm), TSS = number of total spikelets spike^{-1}, ESS = number of effective spikeletes spike^{-1}, NGS = number of grains spike^{-1}, WTS = weight of 1000 seeds, HI = harvest index; V1 = BARI Gom-27, V2 = BARI Gom-33, K0 = 0 kg K ha^{-1}, K1 = 40 kg K ha^{-1} (full as basal), K2 = 40 kg K ha^{-1} (half as basal and half at active tillering stage), K3 = 60 kg K ha^{-1} (full as basal), K4 = 60 kg K ha^{-1} (half as basal and half at active tillering stage), K5 = 80 kg K ha^{-1} (full as basal), K6 = 80 kg K ha^{-1} (half as basal and half at active tillering stage), K7 = 100 kg K ha^{-1} (full as basal), K8 = 100 kg K ha^{-1} (half as basal and half at active tillering stage).

3.1.5 Number of total spikelets spike^{-1}

The effect of potassium management on number of total spikelets spike^{-1} was significant. The highest number of total spikelets spike^{-1} (16.65) was obtained with the treatment 80 kg K ha^{-1} when applied as split (half as basal and half at active tillering stage), caused an increase by 22.15% over the control. Lowest (13.63) was achieved from no K application treatment (Table 1). Number of total spikelets spike^{-1} was significantly affected by the interaction of variety and potassium management at 5% level of significance (Table 1). The highest number of total spikelets spike^{-1} (17.50) was produced from the treatment combination of BARI Gom-33, 80 kg K ha^{-1} when applied as split (half as basal and half at active tillering stage).

3.1.6 Number of sterile spikelets spike^{-1}

Variety had significant influence on number of sterile spikelets spike^{-1} at 1% level of probability. The highest sterile spikelets spike^{-1} (1.61) was found at BARI Gom-27 and lowest (1.51) was found at BARI Gom-33 (Table 1). Potassium management had a significant influence on number of sterile spikelets spike^{-1}. The highest number of sterile spikelets spike^{-1} (2.05) was observed on no K application treatment and lowest (1.33) was observed on both split and basal application of K treatment with 80 kg K ha^{-1} which was statistically similar with basal and split application of K at 60 and 100 kg K ha^{-1} (Table 1). Variety and potassium management had significant influence on number of sterile spikelets spike^{-1} at 5% level of probability. The highest number of sterile spikelets spike^{-1} (2.10) was achieved from BARI Gom-27 with no fertilizer application treatment and lower (1.23) was achieved from BARI Gom-33 at 80 kg K ha^{-1} with split application treatment (half as basal and half at active tillering stage) (Table 1).

3.1.7 Number of grains spike^{-1}

The effect of variety on number of grains spike^{-1} was significant. The highest number of grains spike^{-1} (47.06) was obtained from BARI Gom-33 and the lowest number of grains spike^{-1} (45.76) was obtained from BARI Gom-27 (Table 1). The effect of potassium management on number of grains spike^{-1} was significant. The highest number of grains spike^{-1} (47.62) was found in the treatment split application of K (half as basal and half at active tillering stage) at 80 kg K ha^{-1} which was statistically similar to basal application of K at 80 kg K ha^{-1} and split application of K at 60 kg and 100 kg K ha^{-1}. Application of K at 80 kg ha^{-1} caused an increase number of grains spike^{-1} by 11.73% to control. The lowest number of grains spike^{-1} (42.62) obtained from no K application treatment (Table 1). Variety and potassium management had significant influence on number of grains spike^{-1} at 5% level of probability. The highest number of grains spike^{-1} (48.33) was found in the treatment combination of BARI Gom-33, 80 kg K ha^{-1} and split application (half as basal and half at active tillering stage). The lowest number of grains spike^{-1} (41.40) was achieved from the treatment combination of BARI Gom-27 and without potassium condition (Table 1).

3.1.8 1000-grain weight

Variety had a significant effect on 1000-grain weight of wheat at 1% level of probability. The highest 1000-grain weight (49.67 g) was produced by BARI Gom-33 and lowest (37.24 g) by BARI Gom-27 (Table 1). Potassium management had significant influence on 1000-grain weight of wheat. The maximum 1000-grain weight (45.50 g) was found in crop fertilized with split application of K at 80 kg K ha^{-1} (half as basal and half at active tillering stage) and lowest (38.77 g) was found in control plot (Table 1). At the treatment receiving K at 80 kg ha^{-1} applied as split giving an increase of 17.5% 1000- grain weight over the control. Variety and potassium management had a significant influence on 1000-grain weight of wheat. The highest 1000-grain weight (51.50 g) was found in the treatment combination of BARI Gom-33 sown at 80 kg K ha^{-1} and split application (half as basal and half at active tillering stage) which was statistically identical to basal application of K at 80 kg K ha^{-1} and both the basal and split application of K at 60 and 100 kg K ha^{-1}. The lowest number of 1000-grain weight (32.10) was observed in the treatment combination of BARI Gom-27 and no K application condition (Table 1).

3.1.9 Grain yield

Variety had significant influence on grain yield of wheat at 1% level of probability. The highest grain yield (4.19 t ha^{-1}) was found in BARI Gom-33 and lowest (3.53 t ha^{-1}) was found in BARI Gom-27 (Fig. 1). Potassium management had significant influence on grain yield at 1% level of probability. The highest grain yield (4.37 t ha^{-1}) was obtained from split application of K at 80 kg K ha^{-1} (half as basal and half at active tillering stage). The lowest (2.58 t ha^{-1}) was obtained from no K application treatment (Fig. 2). The grain yield was increased by 69.37% over the control at the treatment K receiving at 80 kg K ha^{-1} when applied as split. Variety and potassium management had significant influence on grain yield at 5% level of probability. The highest grain yield (4.77 t ha^{-1}) was achieved in the treatment combination of BARI Gom-33 grown at 80 kg K ha^{-1} as split application (half as basal and half at active tillering stage). And lowest (2.37 t ha^{-1}) was observed on BARI Gom-27 and no K application treatment (data not shown).

3.1.10 Straw yield

Variety had significant influence on straw yield of wheat at 1% probability. The highest straw yield (6.49 t ha^{-1}) was found in BARI Gom-33 and lowest (5.96 t ha^{-1}) was found in BARI Gom-27 (Fig. 1). Potassium management had significant influence on straw yield at 1% level of probability. The highest straw yield (6.58 t ha^{-1}) was achieved from the treatment 100 kg K ha^{-1} with basal application which was statistically identical to split application of K at 100 kg K ha^{-1} and both the basal and split application of K at 80 K ha^{-1} and lowest (5.12 t ha^{-1}) was achieved from no K application treatment (Fig. 2). Variety and potassium management had a significant influence on straw yield at 5% level of probability. The highest straw yield (6.83 t ha^{-1}) was found in the treatment combination of BARI Gom-33 and 80 kg K ha^{-1} when applied as basal. The lowest (4.83 t ha^{-1}) one was obtained from the treatment combination of BARI Gom-27 and no K application treatment (data not shown).

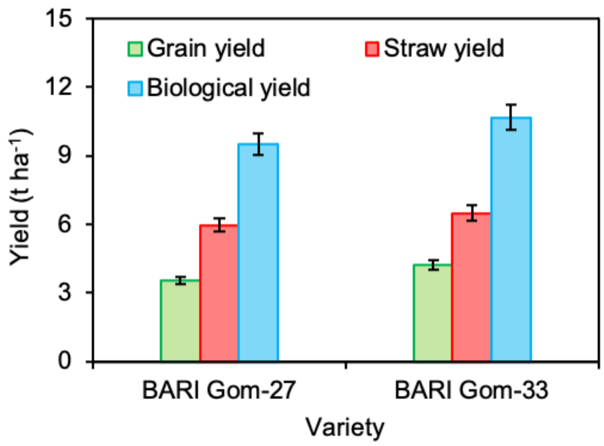

Figure 1. Effect of variety on yield of wheat. Bar represents standard error of means

3.1.11 Harvest index

Variety had significant influence on harvest index of wheat at 1% level of probability. The highest harvest index (39.04%) was observed on BARI Gom-33 and lowest (36.99%) one was observed on BARI Gom-27 (Table 1). Potassium management had a significant influence on harvest index at 1% level of probability. The highest harvest index (39.98%) was obtained from split application of K (half as basal and half at active tillering stage) at 80 kg K ha^{-1} and lowest (33.52%) was obtained from no potassium application treatment (Table 1). Harvest index showed significant effect to interaction of variety and potassium management. The highest harvest index (41.44%) was found in the treatment combination of BARI Gom-33, 80 kg K ha^{-1} and split application of K (half as basal and half at active tillering stage). Lowest (32.87%) was found in the treatment combination of BARI Gom-27 and no K application condition (data not shown).

3.2 Potassium use efficiency of wheat

3.2.1 Potassium agronomic efficiency

Variety had significant influence on potassium agronomic efficiency of wheat at 5% level of probability. The highest potassium agronomic efficiency (3.71%) was obtained from BARI Gom-33 and lowest (3.38%) one was obtained from BARI Gom-27 (Fig. 3). The highest potassium agronomic efficiency (5.08%) was achieved from split application of K (half as basal and half at active tillering stage) with 40 kg K ha^{-1} (Fig. 3). Potassium agronomic efficiency showed significant effect to interaction of variety and potassium management. The highest potassium agronomic efficiency (5.50%) was found in the treatment combination of BARI Gom-33, 40 kg K ha^{-1} and split application of K at sowing and active tillering stage (Table 2).

3.2.2 Apparent K recovery efficiency

Potassium management had a significant influence on K apparent recovery efficiency at 1% level of probability. The highest apparent K recovery efficiency (27.50 kg kg^{-1}) was achieved from the treatment 40 kg K ha^{-1} applied as split (half as basal and half at active tillering stage) (Fig. 3). Apparent K recovery efficiency showed significant effect to interaction of variety and potassium management (Table 2). The highest apparent K recovery efficiency (29.17 kg kg^{-1}) was found in the treatment combination of BARI Gom-33 and 40 kg K ha^{-1} applied as split (half as basal and half at active tillering stage).

4 Discussion

Potassium (K) being an essential macronutrient has an important role in plant processes such as nutrients translocation and nutrient uptake, activation of enzymes, synthesis of protein, cellulose and starch, and consequently enhances crop yield and quality (Epstein and Bloom, 2005). Potassium is known to improve the yield and quality parameter of crops.

Plant height is an important component of straw yield and may also affect grain yield. In the present study, K application at a rate of 80 kg ha^{-1} as split had resulted in a 14.4% increase in plant height over the control. The increasing in plant height due to application of increased level of potassium might be associated with stimulating effect of potassium on various physiological processes including cell division and cell elongation of the plant. In the current research, application of potassium at 80 kg ha^{-1} as split caused an increasing number of tillers and spikelets

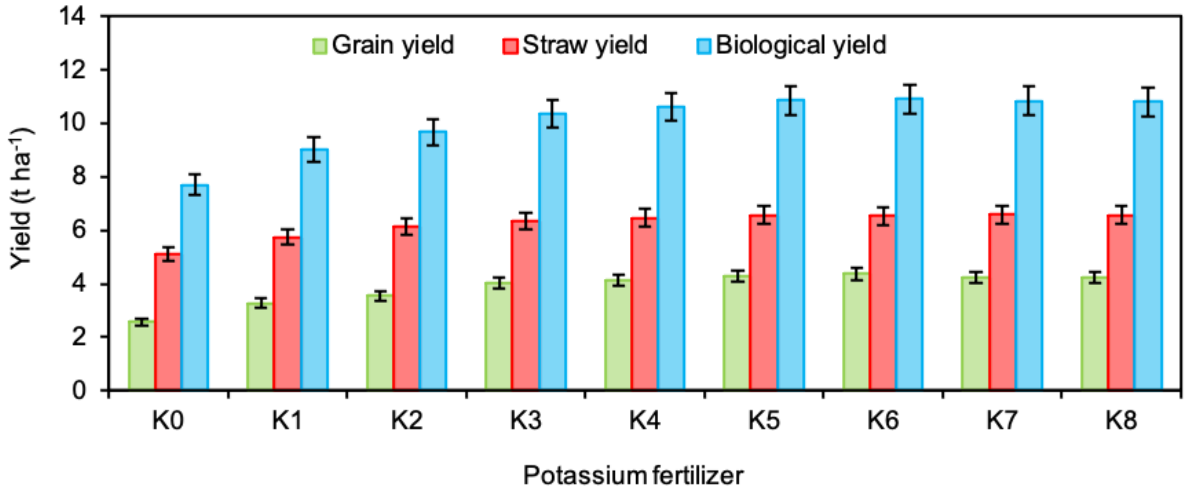

Figure 2. Effect of potassium management on yield of wheat. Bar represents standard error of means, K0 = 0 kg K ha^{-1}, K1 = 40 kg K ha^{-1} (full as basal), K2 = 40 kg K ha^{-1} (half as basal and half at active tillering stage), K3 = 60 kg K ha^{-1} (full as basal), K4 = 60 kg K ha^{-1} (half as basal and half at active tillering stage), K5 = 80 kg K ha^{-1} (full as basal), K6 = 80 kg K ha^{-1} (half as basal and half at active tillering stage), K7 = 100 kg K ha^{-1} (full as basal), K8 = 100 kg K ha^{-1} (half as basal and half at active tillering stage

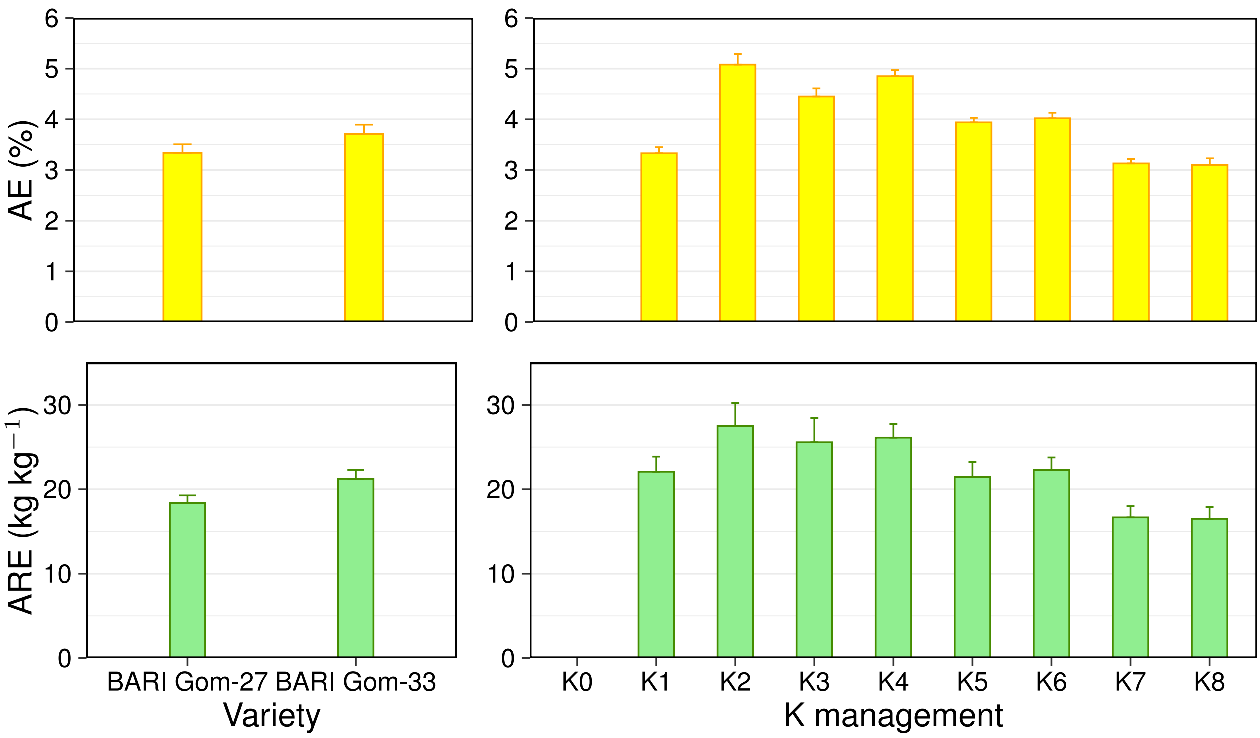

Figure 3. Effect of variety and K management on agronomic efficiency (AE) and apparent recovery efficiency (ARE) of K by wheat. Bar represents standard error of means. V1 = BARI Gom-27, V2 = BARI Gom-33, K0 = 0 kg K ha^{-1}, K1 = 40 kg K ha^{-1} (full as basal), K2 = 40 kg K ha^{-1} (half as basal and half at active tillering stage), K3 = 60 kg K ha^{-1} (full as basal), K4 = 60 kg K ha^{-1} (half as basal and half at active tillering stage), K5 = 80 kg K ha^{-1} (full as basal), K6 = 80 kg K ha^{-1} (half as basal and half at active tillering stage), K7 = 100 kg K ha^{-1} (full as basal), K8 = 100 kg K ha^{-1} (half as basal and half at active tillering stage

Table 2. Interaction effect of variety and potassium management on potassium use efficiency of wheat

Variety × K management	Agronomic efficiency (%)	Apparent K recovery efficiency (kg kg^{-1})
V1 × K0	0.00e	0.00i
V1 × K1	3.12cd	21.67d-g
V1 × K2	4.67a-c	25.83a-d
V1 × K3	4.20a-d	24.47a-e
V1 × K4	4.63a-d	24.44a-e
V1 × K5	3.75b-d	19.17f-h
V1 × K6	3.90b-d	20.00e-g
V1 × K7	3.07d	15.00h
V1 × K8	3.07d	14.67h
V2 × K0	0.00e	0.00i
V2 × K1	3.53b-d	22.50c-g
V2 × K2	5.50a	29.17a
V2 × K3	4.70a-c	26.67a-c
V2 × K4	5.06ab	27.79ab
V2 × K5	4.12a-d	23.77b-f
V2 × K6	4.13a-d	24.60a-e
V2 × K7	3.20cd	18.33gh
V2 × K8	3.13cd	18.33gh
SE	0.35	1.95
Level of sig.	*	*
CV (%)	11.47	6.43

Means with the same letters or without letters within the same column do not differ significantly; * = Significant at 5% level of probability; V1 = BARI Gom-27, V2 = BARI Gom-33, K0 = 0 kg K ha^{-1}, K1 = 40 kg K ha^{-1} (full as basal), K2 = 40 kg K ha^{-1} (half as basal and half at active tillering stage), K3 = 60 kg K ha^{-1} (full as basal), K4 = 60 kg K ha^{-1} (half as basal and half at active tillering stage), K5 = 80 kg K ha^{-1} (full as basal), K6 = 80 kg K ha^{-1} (half as basal and half at active tillering stage), K7 = 100 kg K ha^{-1} (full as basal), K8 = 100 kg K ha^{-1} (half as basal and half at active tillering stage).

$spike^{-1}$ by 45.25% and 22.15% to the control, respectively. The increase in number of tillers and spikelets $spike^{-1}$ with K application might be due to the timely K availability for vigorous crop growth. K at an optimal amount might have maintained cell turgidity, reduced wilting and loss of water from plants surface. This might provide a favourable environment to the crop for more tillers having higher productive tillers due to K application (Bly and Woodard, 2003). The higher tillers and spikes production with K application was also reported by Khaliq et al. (1999). Ma et al. (2000) also stated that K application promoted spikelet development and increased the number of spikelets $spike^{-1}$. K application beyond 80 kg ha^{-1} was excessive and experimental soils reacted negatively and resulted in a considerable decrease in the tillering capacity (Rashid et al., 2011; Khan et al., 2006). The number of grains $spike^{-1}$ (NGS) is an important yield-contributing character and has a direct effect on the final grain yield of wheat. In the present study, an increasing level of potassium gradually increased the NGS than the control, which might be due to the favourable effects of potassium on nutrient uptake, photosynthetic activity, improving its mobilization (Yassen et al., 2010). Roy (2000) also reported that number of grains per spike of wheat increases with higher K application.

It is important to point out that the increase in K level gradually increased the 1000-grain weight of wheat. It gave the idea that the use of K increased the protein rate, which expanded the grain weight (Khadija et al., 1993). K application beyond 80 kg ha^{-1} had no substantial influence on 1000-grain weight of wheat. The probable reason for no substantial enhancement in wheat yield beyond 80 kg K ha^{-1}, upper level of economic threshold of nitrogen use efficiency beyond 80 kg K ha^{-1}. 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.

The increase in grain yield with K application might be due to the fact that K is involved in the transport of photosynthate and sucrose content within plant tissues, hence resulted in a higher yield (Tisdale et al., 2002). The increased yield due to K application might be due to the better sink development (Sweeney et al., 2000; Sharma, 2005). Lower yields in higher plants under no K application were also reported by a number of researchers (Tisdale et al., 2002; Ali et al., 2006). 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 grain yield. In the current study the higher number of grains spike^{-1}, 1000-grain weight, grain yield, biological yield and harvest index were achieved in plots receiving K at a rate of 80 kg ha^{-1} applied as split (half as basal and active tillering stage) compared to single basal dose. This result was similar to Ali et al. (2019) who found that application of K at a rate of 80 kg ha^{-1} increased yield and yield components.

The application of K in splits leads to higher availability of potassium and lower transformation of potassium into non-exchangeable pool which may result in the better utilization of potassium by crop which regulated the continuous growth of cells and tissues, enhanced N uptake and protein synthesis, improved many physiological growth processes and delayed plant leaf senescence, hence increased the growth parameters of the crop. This is in agreement with the findings of Arabinda et al. (2009). The split application of K can enhance the supply of sucrose, promote the accumulation of starch in the grain, and increase the grain yield (Liang and Yu, 2004).Wheat requires large quantities of potassium; a sustained supply is necessary up to heading stage when the reproduction stage is complete. The higher biological yields might be owing to the cumulative effect and positive contribution of yield contributing characters and because of better plant and vegetative growth characters obtained with the application of potassium in split. The present results are similar to Sweeney et al. (2000) and Sharma (2005) who found a higher wheat yield due to increased grain weight under K application. The current result was similar to Roy (2000) who investigated and found a substantial increase in grain weight of wheat under higher K application.

Potassium rate of 40 kg K ha^{-1} applied as split provided the highest potassium agronomic efficiency (5.08%). The lower a nutrient supply, the higher was its efficiencies. The K agronomic efficiency decreased with the increasing level of the nutrients. The highest apparent K recovery efficiency was 27.50 kg kg^{-1} at K fertilizer rate of 40 kg K ha^{-1} applied as split. At the lower doses, the crop utilized most of the supplied nutrients. The higher doses caused excessive vegetative growth of the crop that hindered the reproductive growth, and consequently, the crop failed to utilize the supplied nutrients effectively. This result was similar to Mojid et al. (2012) and H et al. (2017) who reported that both recovery and agronomic K use efficiency consistently decreased with increasing potassium rates.

5 Conclusion

In optimum K fertilizer rate (80 kg ha^{-1}) and split application practices (one at sowing and one at active tillering stage) with BARI Gom-33 variety gave the highest yield (4.77 t ha^{-1}) than any other varieties and treatments. Grain yield increased gradually increased as K fertilizer level increased up to 80 kg ha^{-1} for both the basal and split application. Yield did not increase statistically after the addition of 80 kg K fertilizer ha^{-1}. Therefore, 80 kg K fertilizer ha^{-1} with split application practices (one at sowing and one at active tillering stage) is recommended for wheat production in K-deficient light soil.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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