

Research Article

Izhar Ali, Asad Ali Khan, Fazal Munsif, Liang He, Aziz Khan, Saif Ullah, Wajid Saeed, Anas Iqbal, Muhammad Adnan, Jiang Ligeng*

Optimizing rates and application time of potassium fertilizer for improving growth, grain nutrients content and yield of wheat crop

<https://doi.org/10.1515/opag-2019-0049>

received November 25, 2018; accepted May 6, 2019

Abstract: Nutrient management is a key component of best agronomic practices for optimal crop production. The continuous use of high yielding genotypes and exhaustive cropping systems has resulted in potassium deficiency. Furthermore, the imbalanced use of nutrients, particularly potassium (K), has resulted in persistent depletion from agricultural soils. To address this issue, a field experiment was conducted to determine the influence of different potassium levels under a split application on yield and yield attributes of wheat crops. The experiment was laid out in a randomized complete block design replicated four times. Five K levels (0, 60, 80, 100 and 120 kg ha⁻¹) and different K application timings (whole dose (Basal) at sowing, equal doses at sowing+ 30 DAS, half dose at sowing+ equal doses at 30 +60 DAS and equal doses at sowing+30+60+ 90 DAS). The findings of the study revealed that potassium levels and their application times substantially influenced yield and yield components of wheat. The application of K at 120 kg ha⁻¹ delayed anthesis and maturity and enhanced chlorophyll content (53), tillers m⁻² (293.4 m⁻²) and increased plant height (97.1cm). The application of K 80 kg ha⁻¹ significantly increased grain protein, nitrogen, phosphorus and potassium

content which resulted in a higher (4227 kg ha⁻¹) grain yield. In the case of K timings application, the higher grain yield (3758 kg ha⁻¹) was achieved when K was applied one time at sowing time. It is concluded that K at the rate of 80 kg ha⁻¹ should be applied in full at sowing for achieving higher wheat production.

Keywords: Potassium split application; Grain crude protein; Grain potassium content; Wheat

1 Introduction

Wheat (*Triticum aestivum* L.) is the major source of food for whole world including Pakistan. It is considered as a staple food in Pakistan and supplies about 60% of the calories and protein in our diet (Khalil and Jan 2002). It is ranked first among the cereal crops by occupying more than 66% of the annual cropping area (Khan et al. 2014). Wheat yield in Pakistan is 30-35% lower than its potential yield by 50% from more advanced countries such as China and Mexico (Afridi et al. 2014). Potassium (K) is the third most important nutrient after nitrogen and phosphorus for better crop growth and development (Brady 1990). The increasing cultivation of exhaustive crops, especially cereals, has resulted in reduced K content in Pakistani soil despite its adequate reserves in our soils (Wallace 2001). The cultivation of high yielding genotypes and the lesser or no use of potassium fertilizers further deteriorate the fertility of our soils and increases the deficiency gap (Tariq et al. 2011). K is not a component of plant structure but has central direct and indirect roles such as enzyme activation and various life processes (Haji et al. 2011). It is mostly preferred as an element for enhancing the qualitative traits of crops (Bajwa and Rehman 1996). The use of potassium is almost negligible and about 0.8 kg K ha⁻¹ is applied by our farmers as compared to 15 kg ha⁻¹ on an average basis in advanced countries (MINFAL 2013). The

*Corresponding author: Jiang Ligeng, Key Laboratory of Crop Cultivation and Farming System, Guangxi University, Nanning 530004, P.R.China, E-mail: jiang@gxu.edu.cn

Izhar Ali, Fazal Munsif, Liang He, Aziz Khan, Saif Ullah, Wajid Saeed, Anas Iqbal, Key Laboratory of Crop Cultivation and Farming System, Guangxi University, Nanning 530004, P.R.China
Izhar Ali, Asad Ali Khan, Fazal Munsif, Department of Agronomy, Faculty of Crop Production Sciences, The University of Agriculture, Peshawar-Pakistan

Muhammad Adnan, State key laboratory of conservation and utilization of subtropical Agro-bioresources Guangxi University, Nanning 530004, P.R.China

lower K application is due to the socio-economic status of our poor farmers and lower return. However, most of our soils have a comparatively sufficient quantity of K in the form of insoluble minerals, but a limited amount is available to the crop during the season. The exchangeable K is $<150 \text{ mg kg}^{-1}$ in most soils, which is the critical limit for K deficiency (Bajwa and Rehman 1996). Furthermore, wheat crops also remove about $4 \text{ kg of K ha}^{-1}$ from the soil upon maturity whereas the same quantity is subjected to leaching with rain and irrigation water (Wallace 2001).

Potassium is an essential nutrient and its availability controls many biochemical and physiological processes in plants such as enzyme activation, photosynthesis, protein synthesis, osmoregulation, energy transfer, stomatal movement, cation-anion balance and stress resistance (Wallace 2001; Ashraf et al. 2011; Wang and Wu 2013 and Khan et al. 2014). Potassium is involved in many metabolic pathways and affects crop quality hence it is often called “the quality element” (Ali et al. 2019). Potassium occupies a critical position for wheat’s physiological requirements (Saifullah et al. 2002) and its uptake occurs faster than N or P (Ravichandran and Sriramachandrasekharan 2011). In wheat, there is a decrease in seed size due to insufficient K and this affects the grain filling duration (Ashraf et al. 2011). The response of crop plants to K application is inconsistent and most of the work is conducted on the specific response of K in pot experiments (Rahmatullah et al. 2002; Wakeel et al. 2005). The continuous cultivation and use of high yielding genotypes have further reduced K content in our soils. 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 potassium and to increase its availability, a split application of K according to the demand of a growing crop is the best agricultural technique. The uptake rate of K in winter wheat from seedling emergence for resuming growth after wintering is very low, thereafter maximum uptake rate appears in the period from resuming growth to booting (Han et al. 1998). Split application of K significantly increased the uptake efficiency, productive efficiency of N and K and 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 K during the growth period has also 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). 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).

Keeping in view the importance of K in soil, plant relation, the current experiment was planned to investigate the split use of K at different rates and times in comparison to the basal dose at sowing on yield and yield components of wheat.

2 Materials and methods

2.1 Experimental site

To study the effect of different potassium levels (K) and application timing (AT) on the yield and quality of wheat, a field experiment was laid out at the Agronomy Research Farm, The University of Agriculture, Peshawar in the winter season of 2014-2015. The experimental site was 340 m above sea level. The soil type was categorized as clay loam having a soil pH of 7.8, EC 1.2 and found to be deficient in N, P and K contents (16 mg kg^{-1} , 8.0 mg kg^{-1} and 50 mg kg^{-1} , respectively).

2.2 Experimental materials

The experiment was arranged in an RCB design with four replications. The land was properly prepared using a cultivator twice, followed by a rotavator for a smooth seedbed. The wheat cultivar Siran-2010 was sown on 20th Nov. 2014 in a plot size of $3 \text{ m} \times 3 \text{ m}$ having 10 rows 30 cm apart. Five levels of K (0, 60, 80, 100, 120 kg ha^{-1}) and four application timings (whole at sowing, equal split at sowing + 30 DAS, half dose at sowing + equal split 30+ 60 DAS, equal doses at sowing + 30+ 60+ 90 DAS) were applied. K was used in the form of sulphate of potassium (SOP). The full dosage of P at the rate of 90 kg ha^{-1} was applied in the form of SSP at sowing. A half dose of the recommended amount of N (120 kg ha^{-1}) in the form of urea was applied at sowing time and the remaining amount of N was applied with the first irrigation. The parameters studied were tillers m^{-2} , days to anthesis, physiological maturity, plant height, chlorophyll content leaf area, leaf area index, Spikes m^{-2} , grains per spike, thousand grain weight, biological yield, grain yield, harvest index, nitrogen content, potassium content, phosphorous content and crude protein content during the experiment.

2.3 Data collection and measurements

Data on tillers m^{-2} of wheat was taken by selecting three rows in each plot and tillers were counted in those rows and converted to tillers m^{-2} using equation 1. Days to anthesis of wheat were observed in all plots by counting the number of days from sowing until the date when more than 70% of tillers formed anthers. Data on leaf area tiller⁻¹ was noted at the anthesis stage. The leaf area per tiller was determined by taking three tillers in each plot and the length and broadest width of each leaf was measured using measuring tape and was multiplied with a correction factor and the average leaf area per tiller was worked out. The correction factor was 0.71 for the wheat crop (Khan et al. 2014). Leaf area index is the ratio of leaf lamina area to ground area as in equation 2. Data on leaf chlorophyll content was recorded as a SPAD value, using the Spad meter by putting the flag leaf on the scanner of the meter and hold for a while (Islam et al. 2014). Days to physiological maturity were obtained by counting the days from the date of sowing to the date when 75% of tillers had become mature in all plots. The indication of maturity was the complete loss of the green color of peduncle, glumes. Data on plant height was recorded by taking the height of 5 tillers at random in each plot and the height from the base to the tip of each tiller was measured using a meter rod including awns and was then averaged. Data on spikes m^{-2} was recorded by counting spikes in three middle rows and were then converted to m^{-2} using the same formula as spikes m^{-2} . Grains spike⁻¹ was noted by counting number of grains per spike in five randomly selected spikes in each plot and was averaged. Data on thousand grain weight was obtained by counting 1000 grains at random from the grain lot of each plot and were measured using an electronic balance. Biological yield was noted by harvesting three rows in the middle of each plot and were dried in an open field for one week and were then weighed and converted to kg ha^{-1} using equation 3. The grain yield was determined by threshing the harvested sample and the grain obtained was weighed and converted to kg ha^{-1} . Harvest index expressed in percentage is the ratio of seed yield to biological yield. It was determined by dividing seed yield by biological yield multiplied by 100. Data on grain nitrogen content was determined by using methods of Kjeldahl as described by Bremner and Mulvaney (1965) while crude protein content was calculated by multiplying grain N content with 5.7 (Aurand et al. 1987). Grain phosphorous was determined by using the phospho- vanademolybdate yellow method. Grain potash was determined by using a flame photometer (Whitney et al. 1996).

$$\text{No. of tiller } \text{m}^{-2} = \frac{\text{Tiller counted in four central rows}}{\text{No. of rows} \times \text{Row - row distance} \times \text{Row length}} \quad 1$$

$$\text{Leaf area tiller}^{-1} (\text{cm}^2) = \frac{\text{Tillers } \text{m}^{-2} \times \text{Leaf width} \times \text{Leaf length} \times \text{Factor}}{100 \times 100} \quad 2$$

$$B.Y (\text{kg ha}^{-1}) = \frac{B.Y (\text{kg}) \text{ in four central rows} \times 10000}{\text{Row - row distance} \times \text{No. of rows} \times \text{Row length}} \quad 3$$

2.4 Statistical analysis

The data were statistically analyzed as per the procedure of Jan et al. (2007); opted for a randomized complete block design having four replications. The means of potassium levels and application timings were tested by a least significant difference test at a 0.05 probability level for those parameters which were significantly different at a 5% level of probability.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results

3.1 Growth traits

Potassium levels significantly affected spikes m^{-2} and the plant height of wheat, while application timings except plant height did not affect growth traits. Tillers m^{-2} were also found non-significant under different rates of K. Interaction between K and timings were found non-significant for all studied growth traits (Table 1). Potassium applied at a rate of 120 kg K ha^{-1} resulted in a higher number of tillers m^{-2} (293) followed by 80, 100 and 60 kg K ha^{-1} (287, 284 and 283, respectively). Increasing K levels up to 80 kg ha^{-1} had increased spikes m^{-2} (278) followed by 120 kg K ha^{-1} (259) and 100 kg K ha^{-1} (241). Increasing K levels resulted in taller plants and the tallest plants (97.1cm) were noted at 120 kg K ha^{-1} followed by 100, 80 and 60 kg ha^{-1} (93.0, 89.8 and 87.2cm, respectively). The least number of tillers, spikes m^{-2} and short stature plants (279.6, 237 and 85.5 cm) were noted in control plots (Table 2). The tallest plants (91.3cm) were recorded when K was applied whole at sowing, followed by K application in two splits (Half at sowing + half 30 DAS) and three splits (1/2 at sowing + 25% 30 DAS + 25% 60 DAS) (90.5cm and 90.4cm, respectively). The shorter plants (89.9 cm) were noted in those plots that received K in four equal splits from sowing to 90 DAS with 30 days interval (Table 3).

Table 1: Mean square values of phonological, physiological, yield, yield components and grain nutrients contents of wheat as influenced by K levels and application timings

Plants traits	Potassium levels (K)	Timing K (T)	K × T	Error
Tillers m ⁻²	439.3 ^{ns}	29.55 ^{ns}	55.95 ^{ns}	177
Days to anthesis	143.1 ^{**}	5.813 ^{ns}	1.292 ^{ns}	2.172
Chlorophyll content	226.9 ^{**}	6.931 ^{ns}	4.929 ^{ns}	4.92
Spikes m ⁻²	1290 ^{**}	10.61 ^{ns}	8.94 ^{ns}	14.92
Physiological maturity	143.1 ^{**}	5.813 ^{ns}	1.292 ^{ns}	2.172
Leaf area	260.3 ^{**}	23.63 ^{**}	1.36 ^{ns}	1.7
Leaf area index	0.455 ^{**}	0.014 ^{ns}	0.009 ^{ns}	0.024
Pant height	343.0 ^{**}	6.75 ^{**}	0.74 ^{ns}	2.12
Thousand grain weight	9051251 ^{**}	318898 ^{ns}	48475 ^{ns}	99114
Grains per spike	1290.2 ^{**}	11.61 ^{ns}	8.94 ^{ns}	14.92
Biological yield	8361347 ^{**}	4848322 ^{**}	532341 ^{ns}	437282
Grain yield	9051251 ^{**}	318898 [*]	48475 ^{ns}	99114
Harvest index	62.190 ^{**}	23.81 [*]	9.940 ^{ns}	7.03
Crude protein content	29.389 ^{**}	1.3771 ^{ns}	0.3538 ^{ns}	0.5476
Nitrogen content	0.75237 ^{**}	0.03525 ^{**}	0.00906 ^{ns}	0.01402
Potassium content	0.1383 ^{**}	0.0033 ^{ns}	0.0002 ^{ns}	0.0027
Phosphorous content	0.127 ^{**}	0.003 ^{ns}	0.002 ^{ns}	0.001

Table 2: Phonological, physiological, yield, yield components and grain nutrients contents of wheat as influenced by K levels

Plants traits	0	60	80	100	120	LSD
Till m ⁻²	279.6 b	284.3 b	287.4 ab	283 ab	293.4 a	9.4
Anth	122 e	123 d	125 c	128 b	129 a	1
Chl.	42.69 d	45.72 c	47.76 b	48.33 b	52.95 a	1.78
Sp.m ⁻²	237 d	245 c	278 a	241 b	259 b	8.1
LA	108.0 e	109.8 d	112.2 c	114.4 b	118.3 a	0.92
LAI	3.01 d	3.12 cd	3.22 bc	3.23 b	3.47 a	0.1
BY(kg ha ⁻¹)	9688 d	10248 d	11490 a	11171 ab	10831 c	468
GY (kg ha ⁻¹)	2383 d	3317 c	4227 a	3995 b	3993 b	223
HI (%)	29.80 b	30.59 b	34.65 a	30.06 b	31.39 b	1.87
GCPC (%)	8.67 d	10.11c	12.17 a	10.33 c	11.51 b	0.52
PM	152 e	153 d	155 c	158 b	159 a	1.04
PH (cm)	85.5 e	87.2 d	89.8 c	93.0 b	97.1 a	1.03
TGW (g)	37.0 d	38.4 c	42.2 a	41.3 ab	41.1 b	1.01
GS	33.68d	38.0c	54.06a	51.06b	50.25b	2.73
GNC (%)	1.38d	1.61c	1.94 a	1.65 c	1.84 b	0.08
GKC (%)	0.262d	0.376c	0.539a	0.471b	0.469b	0.04
GPC (%)	0.2021c	0.3153b	0.4490a	0.4228a	0.4198a	0.034

Till (Tiller m⁻²), Anth (Days to anthesis), Chl (Chlorophyll SPAD), SP (Spikes m⁻²), LA (Leaf area), LAI (Leaf area index), BY (Biological yield), GY (Grain yield), HI (Harvest index), GCPC (Grain crude protein content), PM (Physiological maturity), PH (Plant height), TGW (Thousand grain weight), GS (Grain per spike), GNC (Grain nitrogen content), GKC (Grain potassium content) and GPC (Grain phosphorous content).

Table 3: Phonological, physiological, yield, yield components and grain nutrients contents of wheat as influenced by K application timings

Plants traits	T1	T2	T3	T4	LSD
Till m ⁻²	284.8	286.6	284.3	286.6	Ns
Anth	126 a	125 b	125 b	125 b	0.93
Chl.	47.46	48.3	47.31	46.9	Ns
LA	114.1a	112.4b	112.3b	111.5c	0.83
LAI	3.25	3.22	3.19	3.19	Ns
PM	156 a	155 b	155 b	155 b	0.93
Sp.m ⁻²	257	253	252	246	Ns
PH (cm)	91.3 a	90.5 ab	90.4 b	89.9 b	0.9
TGW (g)	40.3	40.1	40	39.6	Ns
GS	46.3 a	45.1ab	43.9b	43.7b	2.4
BY(kg ha ⁻¹)	11213 a	10882 ab	10596 b	10051 c	418.7
GY (kg ha ⁻¹)	3758 a	3586 ab	3520 b	3468 b	199
HI (%)	31.51 a	32.43 a	31.44 ab	29.81 b	1.67
GCPC (%)	10.81	10.64	10.6	10.19	ns
GNC (%)	1.72	1.7	1.69	1.63	ns
GKC (%)	0.441	0.43	0.415	0.408	ns
GPC (%)	0.3628	0.382	0.3591	0.342	ns

Till (Tiller m⁻²), Anth (Days to anthesis), Chl (Chlorophyll SPAD), SP (Spikes m⁻²), LA (Leaf area), LAI (Leaf area index), BY (Biological yield), GY (Grain yield), HI (Harvest index), GCPC (Grain crude protein content), PM (Physiological maturity), PH (Plant height), TGW (Thousand grain weight), GS (Grain per spike), GNC (Grain nitrogen content), GKC (Grain potassium content) and GPC (Grain phosphorous content).

3.2 Phenology

Days to anthesis and the physiological maturity of wheat was considerably altered by K levels. The timing application and K levels interaction was also found to be non-significant for both wheat anthesis and maturity (Table 1). Increasing potassium up to 120 kg K ha⁻¹ delayed anthesis and maturity (129 and 159, respectively) followed by 100 and 80 kg K ha⁻¹ for days to anthesis (125, 123, respectively) and for physiological maturity (158 and 155, respectively). Control plots reached anthesis and maturity early (122 and 155 days, respectively) as shown in Table 2. Physiological maturity delayed (156) in plots which received K in whole at sowing time. Maturity (155) was early when K was applied in splits (Table 3).

3.3 Physiological traits

Data on chlorophyll content, leaf area and leaf area index are shown in Table 1. Significant differences among potassium levels were recorded in the mentioned physiological traits of wheat while application timings except leaf

area and interaction between both the factors remained non-significant for all studied physiological traits. The higher chlorophyll content, leaf area and leaf area index (52.95, 118.3 cm² and 3.74, respectively) was noted in those plots that received K at rate of 120 kg ha⁻¹ followed by 100 and 80 kg ha⁻¹ for chlorophyll content (48.3 and 47.7, respectively), leaf area (114.4 and 112.2 cm², respectively) and leaf area index (3.23 and 3.22, respectively). Control plots had the least chlorophyll content (42.69), leaf area tiller⁻¹ (108 cm²) and leaf area index (3.01). In the case of the application timings, the highest leaf area tiller⁻¹ (114 cm²) was recorded in those plots that received whole potassium at sowing time. It was followed by K applications in two equal splits (at sowing and 30 DAS) and three splits (1/2 at sowing + 1/4th both 30 and 60 DAS) (112.4 cm²) and 112.3 cm², respectively). The lower leaf area (111.5 cm²) of wheat was noted in plots received K in 4 equal splits (at sowing 30, 60 and 90 DAS).

3.4 Yield components and yield traits

Number of grains per spike and thousand grain weight of wheat were significantly affected by potassium appli-

cation. Grain, biological yield and harvest index were also considerably affected by K fertilization. Application timings had significantly influenced yield while TGW was not affected by the timings of K application. Interaction between K and T was found to be non-significant for grains per spike and TGW, biological and grain yield (Table 1). K at rate of 80 kg ha⁻¹ had resulted in a larger number of grains spike⁻¹ (54.06) and heavier grains (42.2 g). It was followed by 100 and 120 kg K ha⁻¹ for grains per spike (51.06 and 50.25, respectively) and thousand grain weight (41.3 g and 41.1g, respectively). The lesser number of grains spike⁻¹ (33.68) and 1000 grain weight (37g) was noted in plots where no potassium was applied. Greater grain and biological yields were recorded in those plots where K was applied at a rate of 80 kg ha⁻¹ (4227 and 11490 kg ha⁻¹, respectively) followed by 120 and 100 kg K ha⁻¹ for grain yield (3995 and 3993 kg ha⁻¹) and biological yield (11171 and 10831 kg ha⁻¹, respectively). The least grain and biological yield (2383 and 9688 kg ha⁻¹, respectively) was recorded in control plots.

The higher grain and biological yield (3758 and 11213 kg ha⁻¹) was achieved in plots receiving whole K at sowing followed by K applied in two equal splits (sowing + 30 DAS) and three splits (1/2 at sowing + 25% both 30 and 60 DAS) (45.1 and 43.8, 3586 and 3520 kg ha⁻¹, 10882 and 10596 kg ha⁻¹, respectively). The lowest grain spike⁻¹, grain and biological yield (43.7, 3468 and 10596 kg ha⁻¹) of wheat was obtained when K was applied in four equal splits (sowing, 30, 60 and 90 DAS). Application of K at a rate of 80 kg ha⁻¹ resulted in a higher harvest index (34.65%), followed by 120 and 60 kg K ha⁻¹ (31.39%, and 30.06%, respectively) while a lower harvest index (29.8%) was recorded in control plots.

3.5 Protein content

Grain protein content (GPC) was significantly influenced by potassium levels. Application timings and Interaction between K and T was found to be non-significant for the grain protein content (GPC) of wheat. Increasing K application had increased GPC (12.17%,) up to 80 kg ha⁻¹ followed by 120 and 100 kg K ha⁻¹ (11.51 and 10.33 respectively). The lower GPC (8.67%) was found in control plots where no K was used.

3.6 Nutrients Content

Grain nitrogen content (GNC), Grain Potassium content (GKC) and grain phosphorous content (GPC) was sig-

nificantly influenced by potassium levels. Application timings and Interaction between K and T was found to be non-significant for all traits except GKC. Increasing the K application had increased GNC, GKC and GPC (1.94, 0.539 and 0.449%, respectively) up to 80 kg ha⁻¹ followed by 120 and 100 kg K ha⁻¹ for GNC (1.84 and 1.65), GKC (0.471 and 0.469) and GPC (0.4228 and 0.4198%, respectively). Lower GNC, GKC and GPC (1.38, 0.262 and 0.202%) were found to be in control plots where no K was used.

3.7 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 (K) is known to improve the yield and quality parameter of higher plants. Many experiments have explored the influence of basal application of K on yield and quality of wheat (Khan et al. 2014; Saifullah et al. 2001; Khan et al. 2017). However, very little work has been done on K timings in response to the yield and quality of wheat. In the present experiment, we investigated the rate and timing of K application on the yield and protein content of wheat. On the other hand, K content in our soils is increasingly deficient due to an imbalanced fertilizer application (Ravichandran and Sriramachandrasekharan 2011). Furthermore, our farmers are failing to apply K fertilizer to wheat due to their poor socio-economic status and no substantial access to nitrogenous and phosphorus fertilizers. Due to these conditions, our soils are becoming deficient in K content especially under a cereal based cropping system. In the present study, K fertilization at a rate of 120 kg ha⁻¹ had resulted in a 7 and 17% increase in tillering and spikes m⁻² over the control, respectively. The increase in tillers and spikes m⁻² with K fertilization 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 favorable environment to the crop for more tillers having higher productive tillers due to K fertilization (Bly and Woodward 2003). The higher tillers and spikes production with K application was also reported by Khaliq et al. (1999). Spikes m⁻² of wheat positively responded to K fertilization. The same was also reported by Tahir et al. (2003) who found that K fertilization had enhanced the tillage of wheat. Likewise, Saifullah et al. reported that uptake was continuously either high or low during the entire growth periods of crop.

Nonetheless, the uptake of K is found to be more active and faster during the early stages of crop growth as compared to N, and P. potassium is usually applied in full at sowing in light soils and in some cases to high texture soil. It can also be applied during the early vegetative stage to the standing crop. David Dunn and Gene Stevens (2005) investigated that K fertilization both prior to sowing and the middle stage had enhanced the rice yield on Missouri soil, Similarly documented by Asif et al. (2007)) that split application of nitrogen fertilizer enhanced crop yield.

Growth parameters such as leaf area per tiller, leaf area index and plant height were enhanced with K fertilization at 120 kg ha⁻¹. Increase in growth traits of wheat might be due to rapid and vigorous vegetative growth under optimal nutrients availability. The same was also reported by Ayub et al. (2002). Taller plants under K fertilization were also investigated by Maqsood et al. (1999). The present findings are also in line with Yang et al. (2003); Hussain et al. (2011) and Aslam et al. (2014) who also found improved growth traits with K fertilization soils. No substantial influence of timings of K fertilization was recorded on tillers and spikes, but taller plants were recorded when whole K was applied at sowing time. The probable reason for taller plants under whole K at sowing might be because the optimal amount of K is provided for vigorous growth as compared to split application where major friction of K might fix with the clay soil and become unavailable to the plant at the right time. Our results are contrary to the findings of Islam et al. (2014) who found that the number of tillers m⁻², plant height and dry matter accumulation was higher with two equal split application of potassium at 80 kg K₂O ha⁻¹ (basal and tiller initiation stage) over a single basal application. In the same manner, Mathukia et al. (2014) also showed that plants were taller when K was applied at a rate of 30 kg K₂O ha⁻¹ as basal + 30 kg K₂O ha⁻¹ at 25 DAS as compared to 60 kg K₂O ha⁻¹ applied as the basal dose.

K had delayed phenological traits such as anthesis and the physiological maturity of wheat. The delay in those traits with K application at 120 kg ha⁻¹ would be due to extended crop growth under an adequate quantity of potassium. The optimal dose of K is also considered necessary for increasing the N and P availability to the crop for better growth. Seilsepour (2007) also reported a delay in physiological maturity with an increase in K fertilization.

3.8 Yield components

K fertilization beyond 80 kg ha⁻¹ had no substantial influence on grain weight of wheat. The probable reason for no substantial enhancement in wheat yield beyond 80 kg ha⁻¹ due to upper level of economic threshold of nitrogen use efficiency beyond 80 kg K ha⁻¹. The increase in grain yield with K fertilization 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). An increase in seed yield with K fertilization could be attributed to a higher number of productive tillers m⁻², and heavier grains (Bundy and Andraski 2004). The increase in grain yield might be due to the collective role of N and K as N improves vegetative growth of wheat and K increases root growth and facilitates the translocation of nutrients and photo-assimilates (Tiwari 2002) increasing K levels, and resulting in enhanced spike m⁻². The increased yield due to K application might be due to the better sink development (Sweeney et al. 2000; Sharma et al. 2005). Lower yields in higher plants under no K fertilization were also reported by a number of researchers (Tisdale et al. 2002; Ali et al. 2006). Though Sweeney et al. (2000) reported a higher yield under low K applied plots. The use of potassium fertilizer increased wheat yield in soils deficient in K (Sweeney et al. 2000; Singh and Sharma 2001). However, the positive influence of K fertilizer was also reported from soils having adequate K availability (Tabatabaei and Ranjbar 2012; Brhane et al. 2017). The present results are in line with Sweeney et al. (2000) and Sharma et al. (2005) who found a higher wheat yield due to increased grain weight under K application. The current results are in line with Roy (1990) who investigated and found a substantial increase in wheat grain weight of wheat under higher K fertilization. The increase in grains per spike of wheat by higher K fertilization were also described by Roy et al. (1990).

3.9 Plant nutrient content

The considerable increase in grain nitrogen, phosphorus and potassium contents with increasing K fertilization over control might be due to the higher uptakes of these nutrients from the soil. As K is involved in several enzymatic activations, it may have increased plant growth and enhanced the uptake of nutrients. Although no substantial effect on the timing of K fertilization was found for the grain PK contents. The higher concentration of these nutrients was achieved for 80 kg K ha⁻¹ and beyond this level no more increase in nutrient accumulation was

detected. The reason for a higher K application has played a central role in enhancing seed protein content, possibly due to improved nitrogen use uptake (Tisdale et al. 2002). The greater availability of amino acids for protein synthesis due to K fertilization might influence the integration of amino acids into grain protein content (Mengel and Kirkby 1987).

4 Conclusion

It is concluded that potassium fertilization has substantially enhanced wheat yield and yield contributing traits and grain protein content. Application of K at a rate of 80 kg ha⁻¹ increased crop growth traits, yield and yield components. A gain of 77.3% and 27.4% in wheat grain yield was achieved with K fertilization at a rate of 80 kg ha⁻¹ over control. Split fertilization of potassium did not improve crop growth and the yield of wheat. The potassium fertilization applied either solely or in two to four splits have no substantial influence on the yield of wheat crop. Potassium fertilization at a rate of 80 kg ha⁻¹ should be applied solely at sowing for achieving higher wheat with improved quality.

Conflict of interest: Authors declare no conflict of interest.

References

- [1] Afrid M.Z., Jan T.M., Munsif F., Khan A., Nabi G., Ahmad M., et al., Nitrogen partitioning and translocation in wheat under fertilizer-N levels, application time and decapitation stress, *J. Biol. Agric. Healthcare.*, 2014, 13, 13-19
- [2] Ali L., Rahmatullah., Aziz T., Ashraf M., Tahir M.A., et al., Differential potassium requirements and its substitution with sodium in different cotton cultivars, *Pak. J. Agr. Sci.*, 2006, 43(3-4), 108-113
- [3] Ali S., Hafeez A., Ma X., Tung S.A., Chattha M.S., Shah A.N., Yang G., et al., Equal potassium-nitrogen ratio regulated the nitrogen metabolism and yield of high-density late-planted cotton (*Gossypium hirsutum* L.) in Yangtze River valley of China, *Ind. Crop. Prod.*, 2019, 129, 231-241
- [4] Ashraf M.A., Ahmad M.S.A., Ashraf M., Al-Qurainy F., Ashraf M.Y., et al., Alleviation of waterlogging stress in upland cotton (*Gossypium hirsutum* L.) by exogenous application of potassium in soil and as a foliar spray, *Crop Pasture Sci.*, 2011, 62(1), 25-38
- [5] Asif M., Amanullah., Anwar M., et al., Phenology, leaf area and yield of spring maize (Cv. Azam) as affected by levels and timings of potassium application, *World Applied Sci. J.*, 2007, 2(4), 299-303
- [6] Aslam M., Zamir M.S.I., Afzal I., Yaseen M., et al., Morphological and physiological response of maize hybrids to potassium application under drought stress, *J. Agr. Res.*, 2011, 51, 443-454.
- [7] Aurand K., Die Trinkwasserverordnung: Einf. u. Erl. für Wasserversorgungsunternehmen u. Überwachungsbehörden. Erich Schmidt, 1987
- [8] Ayub M., Nadeem M.A., Sharar M.S., Mahmood M., et al., Response of maize (*Zea mays* L.) to different levels of nitrogen and potassium fertilizer, *Asian J. Plant Sci.*, 2002, 4(1), 352-354
- [9] Bajawa M.I., Rehman F., et al., Soil and Fertilizer Potassium. In: Soil Science, Bashir, E. and R. Bantle (Eds.). National Book Foundation, Islamabad, Pakistan, 1996, pp. 319
- [10] Bly A.G., Woodard H.J., Foliar nitrogen application timing influence on grain yield and protein concentration of hard red winter and spring wheat, *Agron. J.*, 2003, 95, 335-338
- [11] Bremner, J. M., Total Nitrogen. Edit. C. Black, 1965, Methods of Soil Analysis. Part 2. Amer. Soc. Of Agr. Inc., Publisher, Madison, Wisconsin, USA.
- [12] Brhane H., Mamo T., Tekla K., et al., Potassium Fertilization and its Level on Wheat (*Triticum aestivum*) Yield in Shallow Depth Soils of Northern Ethiopia, *J. Fertil. Pestic.*, 2017, 8, 182, doi:10.4172/2471-2728.1000182
- [13] Bundy L.G., Andraski W., Diagnostic tests for site-specific nitrogen recommendation for winter wheat, *Agron. J.*, 2004, 96, 608-614
- [14] Chaudhry A., Malik J.K., et al., Determination of optimum level of potassium and its effects on yield and quality of maize. *Pak. J. Biol. Sci.*, 2000, 3(2), 194-195
- [15] Dhillon J.S., Eickhoff E.M., Mullen R.W., Raun W.R., et al., World Potassium Use Efficiency in Cereal Crops, *Agron. J.*, 2019, 2(3), 432-441
- [16] Dunn D., Stevens G., Rice potassium nutrition research progress, *Better crops.*, 2005, 89, 15-17
- [17] Epstein E., Bloom A.J., Mineral Nutrition of Plants: Principles and Perspectives, 2nd edition Sunderland, MA: Sinauer Associates, 2005, pp. 1-380
- [18] Haji M.A.A., Bukhsh A., Ahmad R., Iqbal J., Hussain S., Rehman A., Ishaque M., et al., Potassium application reduces bareness in different maize hybrids under crowding stress Conditions, *Pak. J. Agri. Sci.*, 2011, 48, 41-48
- [19] Han J.K., Kim N., Srivastava R.K., et al., Market orientation and organizational performance: is innovation a missing link?, *J. mark.*, 1998, 62(4), 30-45
- [20] Hussain F., Malik A.U., Haji M.A., Malghani A.L., Growth and yield response of two cultivars of Mung bean (*Vigna radiata* L.) to different potassium levels. *J. Anim. Plant Sci.*, 2011, 21, 622-625
- [21] Islam M.R., Haque K.M.S., Akter N., Karim M.A., et al., Leaf chlorophyll dynamics in wheat based on SPAD meter reading and its relationship with grain yield. *Scientia Agriculturae.*, 2014, 8(1), 13-18
- [22] Khalil I.A., Jan A. Cereal crops. In: Cropping technology. A text book of Agriculture New Million Edition. National Book Foundation. pp. 169. Pakistan, Potash Review, 20th Suit, 2002, No. 3:1-8
- [23] Khaliq A., Iqbal M., Salman .M.A., et al., Basra. Optimization of seeding density and nitrogen application in wheat cv.

- Inqlab-91 under Faisalabad conditions, *Int. J. Agri. Biol.*, 1999, 4, 241-243
- [24] Khan A.A., Inamullah., Jan M.T., et al., Impact of various nitrogen and potassium levels and application methods on grain yield and yield attributes of wheat, *Sarhad J. Agric.*, 2014, 30(1), 35-46
- [25] Khan A., Wang L., Ali S., Tung S.A., Hafeez A., Yang G., et al., Optimal planting density and sowing date can improve cotton yield by maintaining reproductive organ biomass and enhancing potassium uptake, *Field crops research.*, 2017, 214, 164-174
- [26] Liang X., Yu Z., Effect of potassium application stage on photosynthetic characteristics of winter wheat flag leaves and on starch accumulation in wheat grains, *J. Appl. Eco.*, 2004, 15(8), 1349-1352
- [27] Lu Q., Jia D., Zhang Y., Dai X., He M., et al., Split application of potassium improves yield and end-use quality of winter wheat, *Agron. J.*, 2014, 106(4), 1411-1419
- [28] Maqsood M., Akbar M., Yousaf N., Mehmood M.T., Ahmad S., et al., Effect of different rate of N, P and K combinations on yield and components of yield of wheat, *Int. J. Agric. Biol.*, 1999, 1, 359-61
- [29] Mathukia R.K., Kapadiya J.K., Panara D.M., et al., Scheduling of nitrogen and potash application in irrigated wheat (*Triticum aestivum* L.), *Journal of Wheat Research.*, 2014, 2, 171-172
- [30] Mengel K., Kirkby E.A., *Principles of Plant Nutrition*. International Potash Institute, Bern, Switzerland, 1987, 347-373
- [31] MINFAL., Ministry for food and Agriculture. *Agricultural Statistics of Pak*. Government of Pakistan. Islamabad., 2013
- [32] Rahmatullah., Gill M.A., Aziz T., et al., Potassium nutrition of field crops on calcareous soils of Pakistan under semi-arid environment. (Abst. p. 40, Plant Sciences). 33rd All Pakistan Science Conference, 2002, 26-28 December, University of Agriculture, Faisalabad, 2002
- [33] Ravichandran M., Sriramchandrasekharan M.V., Optimizing timing of potassium application in productivity enhancement of crops, *Karnataka J. Agric. Sci.*, 2011, 24, 32-37
- [34] Roy R.N. Integrated plant nutrition systems conceptual overview. p 45-48. In: *Proceeding. Symposium on "Integrated Plant Nutrition Management."* National Fertilizer Development Centre, Islamabad, Pakistan, November 2000.
- [35] Saifullah A.M., Ranjha M., Yaseen M., Akhtar M.E., et al., Response of wheat to potassium fertilization under field conditions. *Pak. J. Agri. Sci.* 2002, 2(4), 123-129
- [36] Seilsepour M., Study of wheat grain protein increasing through foliar application of nitrogen after anthesis. *Biaban J.*, 2007, 12, 1-5
- [37] Sharma S.P., Singh M.V., Subehia S.K., Jain P.K., Kaushal V., Verma T.S., et al., Long term effect of fertilizer, manure and lime application on the changes in soil quality, crop productivity and sustainability of maize-wheat system in alfisol of North Himalaya, *Research Bulletin No.2. AICRP on Long Term Fertilizer Experiments, IISS, Bhopal (M.P) and Department of Soils, CSK HPKV, Palampur, H.P.* 2005, pp. 1-88
- [38] Srinivasarao Römhild V., Kirkby E.A., et al., Research on potassium in agriculture: needs and prospects, *Plant Soil.*, 2010, 335(1-2), 155-80
- [39] Sweeney D.W., Grande G.V., Eversmeyer M.G., Whitney D.A. Phosphorus, potassium, chloride and fungicide effects on wheat yield and leaf rust severity. *J. Plant Nutr.*, 2000, 23, 1267-1281
- [40] Tabatabaei S.A., Ranjbar G.H., et al., Effect of different levels of nitrogen and potassium on grain yield and protein of triticale. *Int. Res. J. of Applied and Basic Sci.*, 2012, 3(2), 390-393
- [41] Tahir M.A., Rahmatullah., Gill M.A., Aziz T., et al., Response of wheat and oat crops to potassium application and artificial irrigation with canal water. *Pakistan Journal of Agricultural Sciences.*, 2003, 40(3-4), 114-118
- [42] Tariq M., Saeed A., Nisar M., Mian I.A., Afzal M. Effect of potassium rates and sources on the growth performance and on chloride accumulation of maize in two different textured soils of Haripur, Hazara Division. *Sarhad J. Agric.*, 2011, 27(3), 416-422
- [43] Tisdale S.L., Nelson W.L., Beaton J.D., Havlin J.L., et al., *Soil and Fertilizer Potassium*, pp. 230-265. In: *Soil Fertility and Fertilizers (5th Ed)* Prentice Hall of India, New Delhi, 1995, p. 684
- [44] Tiwari K.N., Phosphorus and potassium fertilization reduces dry weather and late harvest risks. *Fertilizer Knowledge*, 2002, 2, 1-2
- [45] Wakeel A., Aziz T., Hassan A., et al., Growth and potassium uptake of maize (*Zea mays* L.) in three soils differing in clay contents. *Emirates Journal of Agricultural Sciences.*, 2005, 17(1), 57-66
- [46] Wallace L., Sustaining potassium reserves to enhance crops yields. In: *Farming Ahead.*, 2001, 118, 40-41
- [47] Wang Y., Wu W.H., Potassium transport and signaling in higher plants, *Annu. Rev. Plant Biol.*, 2013, 64, 451-476
- [48] Whitney E.N., Rolfs S.R., St. Paul, M.N., et al., Water and the Major Minerals. In: *Understanding Nutrition*, West Publishing Company: Edition, 1996, 7, 448-454
- [49] Yang X.E., Liu J.X., Wang W.M., Li H., Luo A.C., Ye Z.Q., Yang Y., et al., Genotypic differences and some associated plant traits in potassium internal use efficiency of lowland rice (*Oryza sativa* L.). *Nutr. Cycl. Agroecosys.*, 2003, 67, 273-282