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PHYSIOLOGICAL RESPONSE OF SPRING WHEAT TO SEEDING AND POTASSIUM APPLICATION RATES

GHAZANFAR ULLAH*, EJAZ AHMAD KHAN AND ABDUL AZIZ KHAKWANI

Department of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan.
**Corresponding author's email: ghazanfargric@gmail.com.*

Abstract

Potassium application to most of the crops including wheat is scarce in Pakistan, although it is a major element required by the plants. The present study was carried out during 2009-10 and 2010-11 on wheat variety Zam-04 to investigate the role of six potassium six levels i.e., 30, 60, 90, 120, 150 and 180 kg ha^{-1} along with six seeding rates i.e., 50, 75, 100, 125, 150 and 175 kg ha^{-1}. Various physiological, qualitative and grain yield traits were studied including leaf area index, (LAI), leaf area duration (LAD), crop growth rate (CGR), net assimilation rate (NAR) and grain protein content. Increasing the rate of potassium beyond 120 kg ha^{-1}with seed rate of 125 kg ha^{-1}showed decreasing trend for crop growth rate and net assimilation rate, and thus reduced the grain yield. The highest level of leaf area index and leaf area duration could not contribute towards grain yield. However, protein content were increased with combination of highest potassium and lowest seeding rates. Application of potassium fertilizer @ 120 kg ha^{-1} and seeding @ 125 kg ha^{-1} resulted in maximum crop yield.

Key words: Potassium levels, Seed rate, CGR, Yield and wheat.

Introduction

Wheat (*Triticum aestivum* L.) is widely used as main staple food in most parts of the world (Wajid, 2004).Wheat is being cultivated on 9.18 million hectares with production of 25.47 million tons and average yield of 2775 kg ha^{-1} (GoP, 2015). Its annual trade on average basis is about 106 million tonnes from 1999-2003 and by 2020 its demand for whole world can rise to 40 % higher than its availability in 1995-2000. However, for producing such a big output, various resources like seed and fertilizer will be required in optimum range especially in developing countries (Abbas *et al.*, 2013). There is declining trend due in the productivity of soil due to exhaustive farming resulting in the drain of essential plant nutrients from the soil (Anon., 2011) and shortage of nutrients especially potassium in the soil (Grzebisz & Diatta, 2012).

Crop growth depends upon various growth parameters and plant after passing through successful physiological process may end in bumper crop yield. Crop physiological attributes contributiontowards yield is well documented by Mahdavi *et al*., (2006) and Katsura *et al*., (2007) who obtained highest grain yield by improving leaf area duration, crop growth rate, net assimilation rate and relative growth rate of the crop. Siahpoosh *et al*., (2003) also documented that leaf area duration and net assimilation rate had significant impact on crop yield.

Potassium increases crop productive capacity (Hamza & Anderson, 2003) due to its ease of transportation and plant uptake (Wakeel *et al*., 2002) and net assimilation rate, where as its deficiency cause lodging, weaker stem and improper physiological processes (Ross, 2001). In addition, potassium activate numerous enzymes and increase grain protein content (Rehman *et al*., 2008; Gulmezoglu & Aytac, 2010) as well as considered as important factor in growth (Marschner, 2012) due to its physiological role in crop development (Cakmak, 2005). Potassium fertilizer not only support in physiological processes but increase grain yield as well. Ahmad *et al*., (2001) produced highest grain yield where its dosage was 75 kg ha^{-1}. In contrast, Nadeem & Ibrahim (2001) harvested maximum grain yield by using Potassium dose 75 and 150 kg ha^{-1}. The potassium application significantly increased dry matter, crop growth indices and grain yield (Bahmanyar & Ranjbar, 2008). Deficiency of potassium and low dosage may incur yield losses which might be due to intensive cropping and improper utilization of fertilizer responsive behavior of newly introduced cultivars (Iftikhar *et al*., 2010 & Babar *et al*., 2011). Under normal circumstances, our soils due to calcareous nature having low capacity to provide potassium (Bukhsh *et al.*, 2008). Therefore we have to add potassium to obtain maximum grain yield in wheat.

Seed rate is as important as any other input in crop farming practices. Seed rate depends upon many factors viz., time of sowing, seed viability, depth of sowing, type of crop and method of sowing. Crop yield and growth attributes were influenced by planting density (Ozturk *et al*., 2005). Xue *et al*., (2011) recorded maximum grain yield by applying 65 kg ha^{-1}seeding rates but decrease in protein content were noted in heavy seeded plots. On the other hand, wheat yield increment was obtained with the use of 100 kg ha^{-1} (Cheema *et al*., 2003), while Ijaz *et al*., (2002) were satisfied with 120 kg planting rate ha^{-1} to gain maximum yield of wheat during their study period. In some previous studies, 125 and 150 kg ha^{-1}planting densities were recommended to achieve high yield targets for wheat (Nizamani *et al*., 2014 & Farooq *et al*., 2016). By keeping in mind these findings, it is necessary to plan such planting density which is helpful to increase farmer yield as well as save him from additional cost on seed. (Rafique *et al*., 2010).Therefore, the objectives of the study were to find out suitable dose of potassium and optimum seeding rate for enhancing the present low yield of wheat crop in our country.

Materials and Methods

The experiment was conducted at the agronomic research area of Gomal University, Dera Ismail Khan, Pakistan during 2009-10 and 2010-11. Physico-chemical analysis of soil depicted that soil was slightly alkaline with pH 8.22, ECe 2.09 dS/m, SAR 6.15 $(meq/L)^{1/2}$, poor in organic matter content (0.29%), nitrogen (0.014 %) with textural class of silt clay. The maximum and minimum temperature, noted in October was 34ºC and 19ºC, January 16ºC and 5ºC, April 34ºC and 16ºC, respectively. Annual rainfall data recorded during 2009-10 and 2010-11 were 48.5 and 23.3 mm, respectively.

Procedure adopted for conducting research trial: The trial on response of potassium fertilizer along with seeding density on phenology, growth, grain quality and grain yield was initiated for two consecutive years. The design of the trial was randomized complete block design having split plot arrangements with four replications. The seeding densities of 50, 75, 100, 125, 150 and 175kg ha^{-1} were kept in main plot while various potassium doses i.e., 30, 60, 90, 120, 150 and 180 kg ha^{-1} were applied in sub-plots. The size of treatment was 1.8 m x 5 m ($9m^2$). The various sources of fertilizer were urea as nitrogen source, SSP for phosphorous and SOP for potassium. Nitrogen and phosphorous @ 150 and 120 kg ha^{-1} were incorporated into the soil as per recommendation. Complete dosage of phosphorous and half dose of N were utilized at sowing time and remaining half of N was incorporated at the time of first irrigation. The wheat cultivar Zam-04 was cultivated and irrigation was supplied at different critical growth stages to fulfill water requirement. Weeds were controlled by applying broad and narrow leaf weed icides. The remaining management practices were performed as per recommendations. The data on days to 50% heading, days to physiological maturity, Leaf area index (42 and 84 days after sowing), Leaf area duration (42 and 84 days after sowing), Crop growth rate, Net assimilation rate, protein content and grain yield were taken to assess the impact of potassium and seed rate on wheat. The detailed procedure adopted is explained below:

Leaf area index (42 and 84 days after sowing): Leaf area index is the true determinant of photosynthetic efficiency and contributes to significant yield enhancement in crops (Monyo & Whittington, 1973). Leaf area was measured by collecting five plants 42 and 84 days after sowing and measuring their length and width and then multiplied by a constant factor (0.75) to have an authentic value. Leaf area index was then calculated which is the ratio of the leaf surface area to the above ground area occupied by crop (Thomas & Winner, 2000). It explains the overall leaf surface and use of light during growth stages (Zizhen & Hong, 1998).

$$\text{Leaf area index (LAI)} = Leafarea/Groundarea$$

Leaf area duration (42 and 84 days after sowing: The leaf area duration is the maintenance of leaf for the period of growth and denotes the extent and seasonal integral of interception of light (Reddy, 2004). Leaf area duration was determined by multiplying leaf area index with duration of crop.

$$\text{Leaf area duration} = LAIxM$$

where M depicts the total number of weeks in crop growth cycle

Crop growth rate (g m^{-2} day^{-1}): Crop growth rate measures the dry matter increment per unit area in a day. Crop samples were cut and dried in oven at 70 ^{0}C for 48 hours and then these samples for weighed. Crop dry weight m^{-2} in each treatment was taken at 42 and 84 days after sowing the crop. It was calculated 42 and 84 days after sowing and dried and then calculated by putting the values in the formula mentioned below: Gardner *et al*., (1985). Crop growth rate was determined by following formula:

$$\text{Crop growth rate} = W2 - W1/T2 - T1x1/GA$$

where W_2 is the final dry weight (84 days after sowing), W_1 is the previous dry weight of plants (42 days after sowing), T_2 is final weight recording time (84 days after sowing), T_1 is previous weight recording time (42 days after sowing), and GA is land area occupied by crop.

Net assimilation rate (g m^{-2} day^{-1}): The net assimilation rate determines leaf efficiency towards biomass production and calculated by the following formula assigned by (Brown, 1984).

$$\text{Net assimilation rate} = W2 - W1/T2 - T1xLn(LA2) - Ln(LA1)/(LA2 - LA1)$$

where W_1 and W_2 are the dry weight (42 and 84 days after sowing), LA_1 and LA_2 are leaf area (42 and 84 days after sowing) T_2 and T_1 are the time span between two measurements, while Ln is the natural log.

Protein content (%): Protein concentration was determined with the help of Kjeldahl's apparatus, before that, 500 g grain sample was taken and ground. By using Gunning and Hibherds method, 0.5 g sample was digested in 10 mL conc. H_2SO_4 at 400°C for 2-3 hours until solution became transparent. After this, distillation was done in Micro Kjeldahl's apparatus (Jackson, 1973) to determine the nitrogen content in wheat grain. It was then multiplied with 5.71 to convert it into protein. (Peter & Young, 1980).

Grain yield (kg ha^{-1}): The crop was harvested at maturity, dried under the sun and manually threshed and weighed in each treatment and then converted to kg ha^{-1} byusing the formula:

$$\text{Grain yield (kg ha}^{-1}\text{)}=\frac{Grainyieldinfourrows(kg)x10000}{RowtoRowdistancexNumberofrowsxRowlength}$$

Statistical analysis: The data were analyzed statistically using the analysis of variance technique and subsequently least significance difference test was utilized for comparing the treatment means using MSTAT-C computer software by Fisher's analysis of variance technique(Steel *et al*., 1997).

Results and Discussion

Days to 50 % heading: The two earlier and late heading both have drastic effect on crop life cycle which as a result put negative influence on yield. Results exhibited that potassium and seed rates significantly affected days to heading in wheat during 2009-10 and 2010-11 (Table 1). Days to heading in wheat were significantly affected by various potassium doses, seed rate and their interaction. The interaction of 175 kg ha^{-1} seed rate with 180 K kg ha^{-1} resulted in minimum (78.75 and 67.25) days to heading in wheat followed by 80.25 and 69.50 days to heading by the interaction of 150 kg K ha^{-1} with 175 kg ha^{-1} seeding density and 180 kg K ha^{-1} withthe seeding rate of 150 kg ha^{-1}, respectively, during both years. However, delayed heading (97.75 & 95.75 days) was recorded by 50 kg ha^{-1} seeding density combining with 30 kg K ha^{-1}, respectively during two years study period. The probable reason for early heading in treatments having highest dose of potassium @ 180kg ha^{-1}may be the early completion of vegetative growth and hasten start of reproductive phase. However, this early heading did not provide more time for the grains to develop maximum size and weight and hence, maximum yield was not obtained. Similar trend was presented by Khalil *et al*., (2010) who recommended maximum potash dosage for causing earlier wheat heading in wheat.

Days to physiological maturity: The days to physiological maturity were significantly ($p \leq 0.005$) influenced by potassium and seeding rates as indicated in Table 1. These results showed that every increase in potassium had positive influence on physiological maturity, which had provided the farmer an earlier crop. Similar findings were corroborated by Asif *et al*., (2007) who suggested that potassium increases the growth and development process in plant and resultantly brings earlier maturity. The Table (1) indicated significant difference in the results by the combination of potassium and seed rates in affecting the days to physiological maturity in consecutive years. The earliest (123.5 and 116.8) days to physiological maturity were taken by using potassium level of 180 kg ha^{-1} and seeding rates of 50 kg ha^{-1} in two years. However, the maximum (155 and 148.3) days of physiological maturity were witnessed in combination of 30 kg K ha^{-1} with 175 kg ha^{-1} planting density in back to back years of study. Laghari *et al*., (2011) confirmed that higher seed rate and minimum dose of potassium prolonged crop maturity.The prolonged maturity in higher seed rate and minimum potassium application may be the result of higher humidity in soil due to shading effect of dense stand of wheat and low potassium dose also extended the vegetative phase, hence increased maturity period.

Leaf area index (42 days after sowing): Leaf area helps in maximizing crop yield by improving growth phase at vegetative stage of crop. Leaf area index and arrangement of leaf enhance interception of light by magnifying crop canopy and ultimately high photosynthetic efficiency of cultivated crops (Rao *et al*., 2002). Leaf area index data (Table 1) elaborated that potassium levels and seeding rates had produced significantly different results for leaf area index in wheat during 2009-10 and 2010-11. The maximum (0.662 and 0.565) leaf area index was taken by applying potassium dose of 180 kg ha^{-1} along with seed density of 175 kg ha^{-1}, correspondingly, during two years, which was followed by leaf area index of 0.641 & 0.617 in the interaction of 150 and 120 kg K ha^{-1} along with seeding rate of 175 kg ha^{-1}, respectively in previous year and leaf area index of 0.548 & 0.528 by the interaction of 150 and 120 kg K ha^{-1} with 175 kg ha^{-1} seeding density, respectively, in final year. However, lowest (0.180 and 0.131) leaf area index was measured in treatment combination of 30 kg K ha^{-1} with 50 kg ha^{-1} seed rate. The gain in leaf area index may probably be due to fast, prolong and durable enzymatic process as a result of optimum potassium availability during crop cycle. These results were equally supported by Rasheed (2002) and Meille & Pellerin (2008) who reasoned that the highest leaf area index in maximum seeding rate might well be due to competition of plants for capturing more sunlight which enhanced chlorophyll formation and ultimately maximum leaf expansion. Wiersma (2002) also found similar results that maximum seed density increased leaf area index of wheat.

Leaf area index (84 days after sowing): The data in Table 1 depicted that potassium doses and seeding rates had significantly ($p \leq 0.05$) affected the leaf area index (84 days after sowing) in wheat during consecutive years. The leaf area index (84 days after sowing) data were significantly affected potassium and seeding rates individually and in interaction between them. The potassium dose of 180 kg ha^{-1} and seeding rate of 175 kg ha^{-1} in combination produced maximum 5.97 and 5.76 of leaf area index value during parallel years, trailed by 5.74 & 5.59 leaf area indexes by using 150 kg K ha^{-1} along with seeding rate of 175 kg ha^{-1}, correspondingly. The highest level of potassium helped in cell division and cell elongation, which ultimately caused the increase in leaf area, hence resulted in higher leaf area index in treatments with maximum dose of potassium. The minimum leaf area index (2.39 and 2.16) was measured in the connection of 30 kg K ha^{-1} with seed rate of 50 kg ha^{-1} in two year study on potassium and planting rate.

Leaf area duration (42 days after sowing): Leaf area duration contributes pivotal share in photosynthetic efficiency of plant community especially at flag leaf stage which finally provide food to reproductive part of the plant and is helpful in crop yield enhancement. Table 1 showed that potassium levels and seeding rates significantly ($p \leq 0.05$) differed in affecting leaf area duration of wheat 42 days after sowing during 2009-10. The interactive behavior of seeding rate and potassium doses were also proved to provide significant ($p \leq 0.05$) outcome. The longest (3.97 and 3.39) duration of leaves were detected in the combination of 175 kg ha^{-1} seeding rate with 180 kg K ha^{-1} in respective years of study. This trend was followed by leaf area duration 3.84 and 3.70 in the interaction of 175 kg ha^{-1} seeding rate with 150 kg K ha^{-1} and 175 kg ha^{-1} seeding rate with 120 kg K ha^{-1}, respectively in previous year. While 3.29 and 3.16 leaf area duration was recorded by the interaction of 150 kg ha^{-1} potassium level along with 175 kg ha^{-1} seeding rate followed by 175 kg ha^{-1} seeding density and potassium @ 120 kg ha^{-1} in2010-11. However, shortest leaf area duration (1.08 and 0.78) was noted by the interaction of 50 kg seed rate ha^{-1} with 30 kg K ha^{-1}, respectively during two years. The leaf area duration might be due to higher leaf area index which was the result of rapid cell division and elongation and attachment of green leaves for longer period on plant is the result of delayed senescence, hence resulted in maximum leaf area duration in treatments treated with higher dose of potassium. Nadeem *et al*., (2013) conveyed that every increase in potassium increased duration of leaf significantly.

Table 1. Days to 50 % heading, Days to physiological maturity, Leaf area index (42 days after sowing), Leaf area index (84 days after sowing) and Leaf area duration (42 days after sowing) as affected by various potassium levels and seeding rates of wheat during 2009-2010 and 2010-11.

Seeding rates (kg ha^{-1})	Days to 50% heading		Days to physiological maturity		Leaf area index (42 days after sowing)		Leaf area index (84 days after sowing)		Leaf area duration (42 days after sowing)	
	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)
S1 50	89.96 a	88.13 a	131.3 c	122.0 c	0.193 f	0.142 f	2.70 f	2.43 f	1.16 f	0.85 f
S2 75	89.33 ab	85.92 a	134.7 bc	128.8 bc	0.261 e	0.201 e	3.22 e	3.06 e	1.57 e	1.20 e
S3 100	87.79 bc	82.00 b	142.1 abc	132.0 abc	0.335 d	0.269 d	3.76 d	3.63 d	2.04 d	1.61 d
S4 125	87.02 c	77.54 c	146.0 ab	136.1 ab	0.494 c	0.395 c	4.83 c	4.63 c	2.96 c	2.37 c
S5 150	86.50 c	74.75 cd	147.4 ab	139.7 ab	0.556 b	0.461 b	5.25 b	5.06 b	3.33 b	2.76 b
S6 175	84.25 d	71.96 d	151.0 a	142.6 a	0.611 a	0.523 a	5.46	5.29 a	3.66 a	3.14 a
LSD $_{0.05}$	1.960	3.400	13.42	13.36	0.0061	0.027	0.058	0.132	0.017	0.181
Potassium levels (kg ha^{-1})										
K1 30	94.35 a	87.58 a	147.3 a	140.7 a	0.193 f	0.308 f	3.75 f	3.62 f	2.28 f	1.85 f
K2 60	91.54 b	83.96 b	145.0 ab	136.5 b	0.261 e	0.317 e	3.94 e	3.76 e	2.34 e	1.90 e
K3 90	88.50 c	80.63 c	143.0 bc	134.5 bc	0.335 d	0.324 d	4.13 d	3.95 d	2.39 d	1.94 d
K4 120	85.17 d	78.33 d	140.8 cd	131.9 cd	0.494 c	0.337 c	4.32 c	4.13 c	2.49 c	2.02 c
K5 150	83.29 e	76.08 e	139.1 de	129.7 de	0.556 b	0.348 b	4.47 b	4.27 b	2.57 b	2.09 b
K6 180	82.00 f	73.71 f	137.3 e	127.9 e	0.611 a	0.359 a	4.62 a	4.40 a	2.65 a	2.15 a
$LSD_{0.05}$	0.672	1.751	2.783	3.031	0.0057	0.0058	0.061	0.0601	0.0132	0.018
Interaction										
S1K1 50x 30	97.75 a	95.75 a	140.0 g-j	129.0 k-o	0.180 v	0.131 x	2.39 t	2.16 w	1.08z	0.78z
S1K2 50x 60	94.75 bcd	92.50 abc	136.0 j-m	125.5 m-p	0.182 v	0.134 wx	2.49 st	2.28 vw	1.10 z	0.80 z
S1K3 50x 90	90.50 gh	88.75 cd	133.00 k-n	123.3 o-r	0.187 uv	0.138 vwx	2.61 s	2.39 v	1.12 z	0.82 z
S1K4 50x 120	87.50 jk	85.75 d-g	129.3 mno	119.5 pqr	0.198 tu	0.146 uvw	2.79 r	2.55 u	1.19 y	0.87 y
S1K5 50x 150	85.25 j-n	83.75 e-h	126.3 no	118.0 qr	0.204 t	0.151 u	2.89 qr	2.66 tu	1.22 xy	0.90 xy
S1K6 50x 180	84.00 h	82.25 f-j	123.5 o	116.8 r	0.210 t	0.156 u	3.00 q	2.77 st	1.26 x	0.93 x
S2K1 75x 30	96.00 b	94.00 ab	143.0 f-i	136.5 d-j	0.244 s	0.185 t	2.88 qr	2.72 st	1.46 w	1.11 w
S2K2 75x 60	93.25 bc	90.00 bcd	139.5 h-k	131.5 h-n	0.252 rs	0.194 st	3.01 q	2.84 s	1.51 v	1.16 v
S2K3 75x 90	90.25 bc	86.50 def	136.0 j-m	129.8 j-o	0.254 rs	0.196 rst	3.17 p	3.01 r	1.52 v	1.17 v
S2K4 75x 120	87.75 i	83.00 e-i	132.5 lmn	127.3 l-o	0.265 qr	0.205 qrs	3.34 o	3.18 o	1.59 u	1.23 u

Table 1. (Cont'd.).

Seeding rates (kg ha^{-1})	Days to 50% heading		Days to physiological maturity		Leaf area index (42 days after sowing)		Leaf area index (84 days after sowing)		Leaf area duration (42 days after sowing)	
	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)
S2K5 75x 150	85.25 jk	82.50 e-j	129.8 mno	124.3 n-q	0.273 pq	0.210 qr	3.43 no	3.22 pq	1.63 u	1.26 tu
S2K6 75x 180	83.50 l-o	79.50 h-j	127.5 no	123.3 o-r	0.280 p	0.215 q	3.52 n	3.34 op	1.68 t	1.29 t
S3K1 100x 30	95.00 bc	89.75 bcd	146.3 c-h	141.0 a-e	0.319 o	0.251 p	3.40 no	3.30 opq	1.91 s	1.50 s
S3K2 100x 60	92.25 ef	86.75 de	144.3 e-i	135.0 e-k	0.327 no	0.259 op	3.54 mn	3.42 o	1.96 r	1.55 r
S3K3 100x 90	89.00 hi	83.25 e-h	142.3 f-j	133.0 f-l	0.336 n	0.265 no	3.68 m	3.57 n	2.01 q	1.59 r
S3K4 100x 120	85.03 jkl	80.00 h-j	140.3 g-j	130.3 i-o	0.319 o	0.273 mn	3.85 l	3.70 mn	2.06 p	1.64 q
S3K5 100x 150	83.72 k-n	77.25 klm	140.5 g-j	127.8 k-o	0.352 m	0.280 m	3.98 kl	3.82 m	2.11 o	1.68 pq
S3K6 100x 180	81.75 pqr	75.00 lmn	139.3 i-l	125.0 m-q	0.360 m	0.287 m	4.08 k	3.98 l	2.16 n	1.72 p
S4K1 125x 30	93.88 cde	85.75 d-g	147.8 b-f	144.0 abc	0.449 l	0.358 l	4.32 j	4.15 k	2.69 m	2.15 o
S4K2 125x 60	90.75 fg	82.25 f-k	146.3 c-h	139.0 b-g	0.469 k	0.374 k	4.50 i	4.32 j	2.82 l	2.24 n
S4K3 125x 90	88.25 i	78.50 jkl	146.5 c-g	136.8 c-j	0.477 k	0.384 k	4.71 h	4.53 i	2.86 l	2.30 m
S4K4 125x 120	84.50 j-m	75.75 k-n	146.3 c-h	134.5 e-l	0.503 j	0.402 j	4.88 g	4.72 h	3.02 k	2.41 l
S4K5 125x 150	82.00 opq	73.00 mno	145.0 d-i	132.0 g-m	0.522 i	0.415 j	5.18 f	4.92 g	3.13 j	2.49 k
S4K6 125x 180	82.75 n-q	70.00 opq	144.5 e-i	130.5 i-o	0.541 h	0.435 i	5.40 d	5.12 ef	3.25 h	2.61 ij
S5K1 150x 30	92.75 e	81.75 g-j	151.8 a-d	145.3 ab	0.519 i	0.431 i	4.61 hi	4.64 hi	3.12 j	2.58 j
S5K2 150x 60	90.00 gh	78.75 i-l	150.3 a-e	142.5 a-d	0.530 hi	0.442 hi	4.94 g	4.73 h	3.18 i	2.65 hi
S5K3 150x 90	87.50 i	76.25 k-n	148.5 a-f	140.8 b-e	0.540 h	0.449 h	5.22 ef	5.00 fg	3.24 h	2.69 h
S5K4 150x 120	84.25 j-n	73.00 mno	146.8 b-g	138.5 b-h	0.560 g	0.465 g	5.43 d	5.20 e	3.36 g	2.79 g
S5K5 150x 150	83.25 m-p	70.50 opq	144.3 e-i	136.5 d-j	0.583 ef	0.482 f	5.59 c	5.34 cd	3.50 e	2.90 f
S5K6 150x 180	81.25 qr	68.25 pq	142.8 f-j	134.5 f-l	0.600 d	0.495 ef	5.72 bc	5.43 c	3.60 d	2.97 e
S6K1 175x 30	90.75 fg	78.50 jkl	155.0 a	148.3 a	0.571 fg	0.491 ef	4.91 g	4.76 h	3.42 f	2.94 ef
S6K2 175x 60	88.25 i	73.50 mno	153.5 ab	145.8 ab	0.579 f	0.498 de	5.16 f	4.96 g	3.47 e	2.99 e
S6K3 175x 90	85.50 j	70.50 opq	152.0 abc	143.5 a-d	0.595 de	0.511 d	5.36 de	5.23 de	3.57 d	3.06 d
S6K4 175x 120	82.00 opq	72.50 nop	150.0 a-f	141.3 a-f	0.617 c	0.528 c	5.64 bc	5.41 c	3.70 c	3.16 c
S6K5 175x 150	80.25 rs	69.50 opq	148.8 a-f	139.5 b-f	0.641 b	0.548 b	5.74 b	5.59 b	3.80 b	3.29 b
S6K6 175x 180	78.75 s	67.25 q	146.5 c-g	137.5 c-i	0.662 a	0.565 a	5.97 a	5.76 a	3.97 a	3.39 a
$LSD_{0.05}$	1.647	4.289	6.817	7.425	0.022	0.014	0.149	0.157	0.044	0.049

Different letters represent significant differences according to least significant difference ($p \leq 0.05$)

Table 2. Leaf area duration (84 days after sowing), Crop growth rate (g m^{-2} day^{-1}), Net assimilation rate (g m^{-2} day^{-1}), Protein content (%) and Grain yield (kg ha^{-1}) as affected by various potassium levels and seeding rates of wheat during 2009-2010 and 2010-11.

Seeding rate (kg ha^{-1})	Leaf area duration (84 days after sowing)		Crop growth rate (g m^{-2} day^{-1})		Net assimilation rate (g m^{-2} day^{-1})		Protein content (%)		Grain yield (kg ha^{-1})	
	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)
S1 50	16.20 f	14.84 f	3.63 e	3.26 e	9.12 d	9.00 d	41.31 a	12.89 a	2707 e	2115 d
S2 75	19.37 e	18.37 e	4.78 d	4.30 d	10.58 c	10.21 bc	13.93 b	12.42 b	3326 d	2746 c
S3 100	22.56 d	21.82 d	5.80 c	5.24 bc	11.59 b	11.06 ab	13.65 b	11.99 c	4210 c	3322 b
S4 125	29.00 c	27.80 c	8.02 a	7.00 a	12.86 a	11.90 a	13.12 c	11.40 d	5424 a	4368 a
S5 150	31.55 b	30.37 b	6.36 b	5.65 b	9.98 c	9.27 cd	12.68 d	10.70 e	4600 b	3678 b
S6 175	32.80 a	31.74 a	5.43 c	4.81 cd	8.48 d	7.75 e	12.20	10.18 f	4195 c	3348 b
$LSD_{0.05}$	1.960	0.793	0.409	0.611	0.853	0.944	0.310	0.246	253	447.9
Potassium levels (kg ha^{-1})										
K1 30	22.53 f	21.76 f	3.88 e	3.35 e	7.79 e	7.07 e	11.83 f	10.20 f	3247 f	2552 f
K2 60	23.67 e	22.58 e	4.83 d	4.28 d	9.41 d	8.87 d	12.44 e	10.78 e	3697 e	2951 e
K3 90	24.78 d	23.75 d	5.89 c	5.29 c	11.17 b	10.66 b	13.03 d	11.32 d	4232 c	3389 c
K4 120	25.95 c	24.79 c	7.09 a	6.39 a	12.89 a	12.42 a	13.66 c	11.90 c	4860 a	3941 a
K5 150	26.84 b	25.63 b	6.41 b	5.72 b	11.26 b	10.73 b	14.23 b	12.42 b	4399 b	3540 b
K6 180	27.72 a	26.42 a	5.91 c	5.21 c	10.09 c	9.43 c	14.70 a	12.96 a	4026 d	3204 d
$LSD_{0.05}$	0.365	0.362	0.133	0.142	0.245	0.276	0.174	0.110	84.82	87.70
Interaction										
S1K1 50x 30	14.35 t	12.98 x	2.07 r	1.71 w	5.80 t	5.11 w	12.80 lmn	11.50 j	2030 r	1452 p
S1K2 50x 60	14.98 st	13.70 wx	2.89 q	2.52 v	7.87 qr	7.51 stu	13.43 hij	12.05 i	2375 q	1855 o
S1K3 50x 90	15.68 s	14.37 w	3.78 p	3.42 u	9.93 ijk	9.97 kl	14.02 fg	12.60 fg	2794 nop	2192 mn
S1K4 50x 120	16.75 r	15.30 v	4.77 m	4.40 qr	11.78 efg	12.14 de	14.65 de	13.15 cd	3325 m	2680 kl
S1K5 50x 150	17.38 qr	16.02 uv	4.30 n	3.94 t	10.25 hij	10.34 ijk	15.25 bc	13.65 b	2978 n	2394 m
S1K6 50x 180	18.03 qr	16.63 tu	3.94 op	3.57 u	9.10 mn	8.94 nop	15.70 a	14.40 a	2744 op	2116 n
S2K1 75x 30	17.30 qr	16.34 tu	2.94 q	2.54 v	7.22 s	6.67 v	12.35 opq	11.00 k	2622 p	2075 n
S2K2 75x 60	18.07 q	17.09 t	3.91 op	3.49 u	9.24 lm	8.86 nop	13.00 hij	11.57 j	2921 no	2358 m
S2K3 75x 90	19.03 p	18.07 s	4.96 lm	4.50 pqr	11.33 g	11.00ghi	13.60 gh	12.15 i	3476 lm	2864 jk
S2K5 75x 150	20.59 no	19.53 qr	5.52 ij	5.02 mno	11.70 fg	11.42 fg	14.90 cd	13.27 c	3637 l	3015 j

Table 2. (Cont'd.).

Seeding rate (kg ha^{-1})	Leaf area duration (84 days after sowing)		Crop growth rate (g m^{-2} day^{-1})		Net assimilation rate (g m^{-2} day^{-1})		Protein content (%)		Grain yield (kg ha^{-1})	
	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)	(2009-10)	(2010-11)
S2K6 75x 180	21.15 n	20.07 pq	5.20 kl	4.67 opq	10.72 h	10.29 jk	15.43 ab	13.77 b	3288 m	2783 kl
S3K1 100x 30	20.43 no	19.84 pqr	3.90 op	3.43 u	8.51 nop	7.90 rst	12.02 qrs	10.50 l	3325 m	2636 l
S3K2 100x 60	21.28 mn	20.53 op	4.95lm	4.45 qr	10.45 hij	9.93 kl	12.75 l-o	11.07 k	3871 k	3075 ij
S3K3 100x 90	22.13 m	21.42 no	6.04 g	5.51 ijk	12.33 de	11.91 ef	13.38 h-k	11.63 j	4398 g	3419 e-h
S3K4 100x 120	23.12 l	22.25 mn	7.26 e	6.65 e	14.30 b	13.88 b	14.00 fg	12.43 gh	5055 e	3940 d
S3K5 100x 150	23.90 kl	22.97 m	6.55 f	5.93 gh	12.53 d	12.04 def	14.60 de	12.93 de	4487 g	3552 ef
S3K6 100x 180	24.51 k	23.92 l	6.09 g	5.45 jkl	11.39 g	10.68 hij	15.13 bc	13.38 c	4122 j	3272 ghi
S4K1 125x 30	25.95 j	24.95 k	5.49 ijk	4.84 nop	9.84 jkl	9.14 mno	11.73 st	10.00 m	4170 hij	3381 fgh
S4K2 125x 60	27.01 i	25.95 j	6.63 f	5.92 gh	11.38 g	10.79 g-j	12.23 pqr	10.63 l	4793 f	3884 d
S4K3 125x 90	28.27 h	27.18 i	8.34 c	7.37 c	13.82 bc	12.91 c	12.80 lmn	11.15 k	5585 c	4528 bc
S4K4 125x 120	29.30 g	28.38 h	10.13 a	8.85 a	16.11 a	14.82 a	13.40 hij	11.70 j	6564 a	5333 a
S4K5 125x 150	31.10 f	29.59 g	9.11 b	7.85 b	13.76 bc	12.67 cd	14.00 fg	12.23 hi	5920 b	4698 b
S4K6 125x 180	32.40 d	30.73 ef	8.40 c	7.15 cd	12.23 def	11.04 gh	14.55 de	12.70 ef	5511 cd	4384 c
S5K1 150x 30	27.68 hi	27.85 hi	4.73 m	4.05 st	8.26 opq	7.35 tu	11.30 t	9.30 n	3869 k	3072 ij
S5K2 150x 60	29.69 g	28.41 h	5.66 hi	5.03 mn	9.44 klm	8.75 opq	11.88 rs	9.92 m	4360 gh	3464 efg
S5K3 150x 90	31.37 ef	30.05 fg	6.56 f	5.82 ghi	10.50 hi	9.75 klm	12.40 n-q	10.48 l	4808 f	3839 d
S5K4 150x 120	32.63 d	31.20 de	7.64 d	6.92 de	11.77 efg	11.18 gh	12.95 klm	10.98 k	5346 d	4344 c
S5K5 150x 150	33.58 c	32.09 cd	7.03 e	6.30 f	10.46 hi	9.80 klm	13.52 hi	11.50 j	4871 ef	3923 d
S5K6 150x 180	34.37 bc	32.60 c	6.52 f	5.78 g-j	9.45 klm	8.81 op	14.05 f	12.05 i	4344 ghi	3425 e-h
S6K1 175x 30	29.46 g	28.58 h	4.15 no	3.56 u	7.11 s	6.25 v	10.77 u	8.92 o	3469 lm	2698 kl
S6K2 175x 60	30.99 f	29.82 g	4.90 lm	4.30 rs	8.11 pqr	7.36 tu	11.38 t	9.42 n	3863 k	3073 ij
S6K3 175x 90	32.17 de	31.40 de	5.67 hi	5.11 lmn	9.08 mn	8.40 pqr	11.98 qrs	9.92 m	4334 ghi	3494 ef
S6K4 175x 120	33.86 bc	32.49 c	6.62 f	5.96 fg	10.12 ij	9.50 lmn	12.63 m-p	10.43 l	4859 ef	3964 d
S6K5 175x 150	34.48 b	33.58 b	5.94 gh	5.28 klm	8.85 mno	8.11 qrs	13.13 i-l	10.95 k	4500 g	3619 e
S6K6 175x 180	35.83 a	34.57 a	5.30 jk	4.63 pqr	7.63 rs	6.86 uv	13.32 h-k	11.45 j	4144 ij	3244 hi
$LSD_{0.05}$	0.895	0.899	0.326	0.349	0.600	0.067	0.426	0.270	207.8	214.8

Different letters represent significant differences according to least significant difference ($p\leq0.05$)

Leaf area duration (84 days after sowing): Leaf area duration indicates the magnitude and persist ability of crop during its cycle of development (Gardner *et al*., 1988). Leaf area duration enhancement improves photosynthetic efficiency of plant, chlorophyll formation and ultimate yield. The leaf area duration (Table 2) assured that various potassium doses and seeding rates significantly differed in affecting leaf area in wheat 84 days after sowing during two years of experiment. The interaction of seeding density and potassium dosage also remained significant throughout the study. The maximum (35.83 & 34.57) leaf area duration was recorded by the interaction of 175 kg ha^{-1} seeding rates along with 180 kg ha^{-1} of potassium during 2009-10 and 2010-11. The reason might be the leaf spreading due to space availability, sufficient sunlight and CO_2 capturing by the leaves along with accessibility of plant for nutrients that are provided in optimum quantity. However, these values were followed by (34.48 and 33.58) in combination of 150 kg K ha^{-1} with 175 kg ha^{-1} rate of seeding in 2009-10 and 2010-11. The minimum (14.35 and 12.98) leaf area duration (84 days after sowing) was taken by the wheat crop in potassium and seed rate association of 50 kg ha^{-1} rate of seeding with 30 kg K ha^{-1} in consequent years. This might be due to insufficient potassium in root zone which may have provided minimum amount of potassium to above ground portion of plants and as a result poor performance of wheat crop.

Crop growth rate (g m^{-2} day^{-1}): Crop growth rate is regarded to be a vital physiological index, because it is the representation of the end result of catabolic and anabolic activity with plant canopy architecture. Crop growth rate denotes the authentic tool to estimate the dry matter of crop (Williams *et al.*, 1965). Crop growth is dependent on amount of solar radiation caught by plant during the process of food formation (Jeffrey *et al*., 2005). The crop growth rate as presented in Table 2 that potassium doses and seed rates differed ($p \leq 0.05$) in affecting the crop growth rate in wheat. The increment in potassium level, averaged across seeding rates, delivered significant increase in the wheat crop growth rate. The maximum (10.13 g m^{-2} day^{-1} and 8.85 g m^{-2} day^{-1}) of crop growth rate were calculated in association of 125 kg ha^{-1} seed rate and 120 kg K ha^{-1} during 2009-10 and 2010-11.These findings were corroborated by Hussain *et al*., (2010) who was of the opinion that this might be due to enhancement in soil fertility, nutrients spot availability as well as efficient absorption of potassium in root zone. Beyond this range, it has proved to be detrimental for wheat. Reddy (2004) argued that the use of potassium beyond optimum range had declining effect on crop dry weight. The results are also supported by Ebelhar & Varsa (2000) who were of the opinion that appropriate potassium is necessary for maintaining growth processes in plants. These outcomes about seed rates were also validated by Fukai *et al*., (1990) who reasoned that optimal plant population and vigorous plants per unit area developed proper plant architecture that enhanced light interception, weight of plant and economic yield resulted in huge fresh and dry weight. However, crop growth rate of (9.11 and 8.40 g m^{-2} day^{-1}) were recorded in 125 kg ha^{-1} seeding rate with 150 kg K ha^{-1} and 125 kg ha^{-1} with 180 kg K ha^{-1} in 2009-10. In the 2010-11, crop growth rate of 7.85 and 7.37 g m^{-2} day^{-1} were evident in the combination of 150 kg K ha^{-1} with 125 kg ha^{-1} seeding rate and potassium level of 90 kg ha^{-1} with planting density of 125 kg ha^{-1}, respectively. The lowest crop growth rate (2.07 g m^{-2} day^{-1} and 1.71 g m^{-2} day^{-1}) were generated by the interaction of 50 kg ha^{-1} planting rate with 30 kg K ha^{-1}.

Net assimilation rate (g m^{-2} day^{-1}): The net assimilation rate data (Table 2) revealed that both potassium levels and seeding rates significantly ($p \leq 0.05$) differed in affecting the net assimilation rate (g m^{-2} day^{-1}) of wheat during 2009-10 and 2010-11. The highest net assimilation rate of 16.11 g m^{-2} day^{-1} and 14.82 g m^{-2} day^{-1} was recorded at the potassium level and seeding rate of 120 and 125 kg ha^{-1}, respectively, in succeeding years. These findings were trailed by (13.82g m^{-2} day^{-1} and 13.76g m^{-2} day^{-1}) by using 90 kg K ha^{-1} with 125 kg ha^{-1} planting rate and 90 kg ha^{-1} potassium and 125 kg ha^{-1} seeding density in previous year and net assimilation rate of 13.88 were recorded in combination of 120 kg K ha^{-1} with 100 kg K ha^{-1} of seeding rate followed by 12.91 in the interaction of 90 kg ha^{-1} of potassium dose with 125 kg seed rate ha^{-1} in final year. The seeding rate of 50 kg ha^{-1} along with 30 kg K ha^{-1} showed minimum (5.80 g m^{-2} day^{-1} and 5.11 g m^{-2} day^{-1}) net assimilation rate in consequent years. These results were corroborated by Mahmood *et al*., (1999) and Hussain *et al*., (2010) who proposed the use of potassium for maximizing net assimilation rate in wheat. The highest net assimilation rate could be due to higher crop growth rate recorded by potassium level as well as optimum plant population density which induced maximum light interception and augmented photosynthetic efficiency in wheat. Further increase in seeding rates had deleterious effects on the net assimilation rate in wheat. Dwyer *et al*., (1991) observed increase in leaf area index and net assimilation rate per unit area by enhancing seeding density.

Protein content (%): Potassium is macro element and contributes largely in numerous metabolic processes occurring in plants especially synthesis of protein (Marschner, 1995). The grain protein content data as presented in Table (2) showed that potassium and rate of seeding significantly ($p \leq 0.05$) differed in influencing protein content of grain of both years.The interactive results of seed density and potassium doses also produced significant outcome. The maximum protein content (15.70 % and 14.40 %) were contributed by the combination of planting rate of 50 kg ha^{-1} along with 180 kg ha^{-1} in 2009-10 and 2010-11. The probable logic behind these findings may be the low plant population which minimized plant competition for nutrients as well as space, while higher dosage of potassium made possible the availability of nitrogen which may have contributed to protein enhancement in wheat grain. In addition potassium, directly or indirectly involvement in protein metabolism of crop is well documented (Pettigrew, 2008 and Rehman *et al*., 2008). In addition our results were endorsed by Usherwood (1985) and Haji *et al*., (2009) who significantly increased protein in cereal family of crops by using potassium fertilizer timely and sufficiently. Geleta *et al*., (2002) and Minjian *et al*., (2007) were of the same view that every increase in quantity of seed reduced the level of protein in grain. Gaffar (2007) also supported our findings. However, protein contents (15.43 %) were noted in 75 kg ha^{-1} planting density and 180 kg K ha^{-1} followed by 15.25% protein in grain in the interaction of 50 kg ha^{-1} seeding density with 150 kg ha^{-1}, during 2009-10. In second year, protein contents in grain (13.77%) were obtained in combination of 75 kg ha^{-1} seed rate with 180 kg ha^{-1} of potassium fertilizer succeeded by 13.65% with the use of 50 kg seed rate ha^{-1} and 150 kg potassium ha^{-1}, respectively. The lowest grain protein contents (10.77% and 8.92%) were obtained by incorporating 30 kg K ha^{-1} along with seeding density of 175 kg ha^{-1}, during 2009-10 and 2010-11.

Grain yield (kg ha^{-1}): Grain yield is the sum of three yield components (Fertile tillers, 1000-grain weight and number of grains per spike (Ahmad *et al*., 1988). The grain yield is significantly ($p \leq 0.05$) affected by the use of planting density and potassium doses in parallel years as depicted in Table (2). The highest (6564 kg ha^{-1} and 5333 kg ha^{-1}) grain yield was recorded in the combination of 125 kg ha^{-1} planting density and dosage of 120 kg K ha^{-1} in consecutive years. Tahir *et al*., (2008), Haji *et al*., (2009), Slaton *et al*., (2009), Hamayun *et al*., (2011), Madan & Manjal, (2009), Nawab *et al*., (2011) and Abbas *et al*., (2013) endorsed our findings and concluded that potassium fertilizer in appropriate amount benefited wheat crop. In addition, these outcomes were corroborated by Njuguna *et al*., (2010) who suggested that according to locality and soil status quantity of seed may be adjusted to obtain desirable results. The possible reason could be that most of our soils had a minimum availability to plants due to binding of clay minerals with potassium, therefore, additional amount boasted grain yield beside that this contribution towards yield might well be due to highest number of tillers per unit area and maximum number of grains in a spike. However, this trend was followed by the interaction of 125 kg ha^{-1} planting density and 150 kg K ha^{-1} produced grain yield of 5920 kg ha^{-1} followed by 90 kg K ha^{-1} with 125 kg ha^{-1} seeding rate generated 5585 kg ha^{-1} grain yield in wheat 2009-10,while 150 kg ha^{-1} potassium dosage and 125 kg ha^{-1} treatment recorded 4698 kg ha^{-1} grain yield followed by grain yield of 4528 kg ha^{-1} in interaction of 90 kg K ha^{-1} and 125 kg seed rate ha^{-1} in 2010-11. Whereas, lowest (2030 and 1452 kg ha^{-1}) grain yield was found by the interaction of 50 kg ha^{-1} seed rate and 30 kg ha^{-1} potassium dosage in continuous research trial for two years.

Conclusion

Results indicated the significance of potassium and seeding rates on crop physiology, quality and grain yield. However, for obtaining the higher yield, potassium @ 120 kg ha^{-1} along withseed rate @ 125 kg ha^{-1} will be the appropriate combination under agro-ecological conditions of Dera Ismail Khan.

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