IMPACT OF FOLIAR APPLICATION OF POTASSIUM SULPHATE ON WEED DYNAMICS AND SOME PHYSIOLOGICAL ATTRIBUTES OF RAINFED BREAD WHEAT

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ABSTRACT

An experiment to find out the wheat growth as affected by foliar application of potassium Sulphate (K_2SO_4) on different growth stages under rainfed conditions was conducted at the Agricultural Research Institute, Dera Ismail Khan, Pakistan. Potassium doses viz. 0, 12, 18, 24, 30 and 60 kg ha^{-1} were applied in foliar form at tillering, booting and heading stages of wheat. The course of study revealed that foliar application of K_2O in booting stage produced maximum leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), net photosynthesis rate (NPR) and grain yield, while its application at heading stage produced maximum net assimilation rate (NAR). Among different doses, the application of potassium at the rate of 60 kg ha^{-1} potassium at the rate of 60 kg ha^{-1} produced maximum growth and yield and its components during two consecutive cropping seasons of wheat crop while weed density (m^{-2}), relative weed density (%), fresh weed biomass (g m^{-2}) and dry weed biomass (g m^{-2}) influenced non-significantly for both the years. These findings suggest that foliar application of potassium sulphate @ 60 kg ha^{-1} along with recommended dose of nitrogen (120 kg ha^{-1}) and phosphorus (90 kg ha^{-1}) is the most suitable for successful wheat production under rainfed conditions.

Keywords: CGR, foliar application, K_2SO_4 , LAI, LAD, Potassium Sulphate, NPR, NAR, weed flora.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important and widely cultivated crop in Pakistan. It is the principal source of nourishment and its requirement is increasing every year due to increasing population and stagnant yield per unit area in the country. This crop covers 70% of winter and 37% of total cropped area in the country.

Pakistan is an agricultural country with a variable type of climate in which two third of the area is arid. A large acreage lying in the central and southern Pakistan is highly arid, while the northern part is humid except the extreme northern mountains, which are relatively dry.

The areas in the south experience the arid and semi arid climate with low precipitation and high temperature (Chaudhry and Rasul, 2004). Potassium is an important nutrient that is required in huge amount for normal plant growth and development. Its deficiency symptoms appear as yellowish white mottling to a light yellowish green color and yellow spots appearing between the veins. Its availability plays an important role in translocation of carbohydrates, photosynthesis, water relations, resistance against insects and diseases and keep balance between monovalent and bivalent cations (Brar and Tiwari, 2004).

Among various growth limiting factors, weeds compete with crop for light, water, space and nutrients. Annual as well as biennial weeds competition is very crucial with dry land wheat production, especially during the critical growth stages. Weeds harm wheat crop on account of their rapid regenerative powers (Marwat *et al.*, 2013). Different weeds management methods have been used without threshold level of individual weed in past. The reason behind is that weed flora in crop and their competitive abilities changes with different environment (Rehman *et al.*, 2015). Drought stress is another most important threat for the reduction of growth and yield of a plant (Souza *et al.*, 2004). The shortage of water occurs in low rainfall regions and most wheat is cultivated in such semi arid regions (Deng *et al*., 2004). El-Ashray and Kholy (2005) reported that the negative effect of drought could be decreased by foliar application of potassium to plants. Plants translocate this potassium to all parts, in return yield is increased. The crop growth rate is decreased when it is not applied sufficiently (Hermans *et al*., 2006).

Various adaptive mechanisms in the plants have been developed under stress conditions for its survival in unfavorable conditions. Potassium is applied to enhance drought tolerance in plants by mitigating harmful effects through higher translocation rate and keeping the water balanced. Its application promotes photosynthesis, osmoregulation, transpiration, protein synthesis, opening, and closing of stomatal pores (Cakmak, 2005). It has been reported that during stress conditions, ROS formation was induced, oxidation damaged to cells occurred, and K requirements increased accordingly (Foyer *et al*., 2002). This increased need under drought conditions showed that potassium is required for photosynthesis and CO_2 fixation, as under water deficit conditions caused stomatal closure and the CO_2 fixation decreased accordingly. Mengel and Kirkby (2001) observed that due to low potassium concentration, ROS production was induced under drought conditions that closed the stomata. It has been reported that seed from potassium deficient plants are generally small and shriveled, whereas suitable amount of K can improve the seed quality (Fusheng, 2006). Keeping all this in view, the present study was conducted to find out the economical dose and growth stage of foliar potassium application for low weed flora and high photosynthetic activities of dry-land wheat.

MATERIALS AND METHODS

This experiment was carried out to find out the effect of foliar application of Potassium Sulphate K_2SO_4 @ 0 and 12 kg

(20% of recommended Fertilizer Dose-RFD), 18 kg (30% of RFD), 24 kg (40% of RFD), 30 kg (50% of RFD) and 60 kg ha^{-1} (100% of RFD) at tillering, booting and heading stages on wheat variety Hashim-8. The experiment was laid out in randomized complete block design with two factors (Factor-A in main plots comprised of three crop growth stages, while potassium doses were assigned to Factor-B. The experiment was replicated 3 times. Each sub-plot measured 5 x 1.8 m^2. The nitrogen (120 kg ha^{-1}) and phosphorus (90 kg ha^{-1}) for all treatments were also applied equally to all the plots as basal dose. The physico-chemical analysis of soil is presented in Table-1. Metrological data consisting of temperature, rainfall and relative humidity is given in Tables 2 and 3.

Data on weed density (m^{-2}), relative weed density (%), fresh weed biomass (g m^{-2}) and dry weed biomass (g m^{-2}), leaf area indices (42 and 84 DAS), leaf area duration (42 and 84 DAS), crop growth rate (g m^{-2} day^{-1}), net assimilation rate (g m^{-2} day^{-1}), net photosynthesis rate (µ mol m^{-2} sec^{-1}) and grain yield (kg ha^{-1}) were recorded as per standard procedures and subjected to analysis of variance technique as suggested by Steel *et al*. (1997). Turkey's Honestly Significant Difference (HSD) Test (Gomez and Gomez, 1984) was used for mean comparison when F-ratio was statistically significant ($p<0.05$) analysis of variance showed test.

RESULTS AND DISCUSSION

Weed parameters

The data regarding weeds parameters are presented in Tables 4 and 5. The prominent species infesting the experiments were field bindweed *(Convolvulus arvensis* L.*)* and camelthorn *(Alhagi camelorum* Fischer*).* There were non-significant differences in weed density (m^{-2}), relative weed density (%), fresh weed biomass (g m^{-2}) and dry weed biomass (g m^{-2}) 30 and 60 days after sowing (DAS). The comparable weed population, fresh and dry biomass in various K doses applied at different growth stages of wheat might be related to hand weeding at 30 and 60 days after sowing and suppression of weed growth, as they were uprooted largely and later smothered by the wheat crop. The weeds were suppressed largely due to continuous depletion of moisture under the soil surface because of no irrigation.

Leaf area indices (42 and 84 DAS)

Leaf area index was significantly ($p\leq0.05$) affected by K application on growth stages, doses and their interaction at 42 DAS during the study years (Table-6a). Maximum LAI (0.13) was obtained when K was applied at booting stage of crop, which was statistically similar to the K applied at tillering stage, while minimum LAI (0.08) was recorded at heading stage of crop. Among different K doses, maximum (0.16) LAI was recorded when K was applied @ 60 kg ha^{-1}, while minimum (0.06) in control plots. The interaction revealed maximum and statistically at par (0.19 and 0.17) LAI at booting and tillering stages, respectively when K was applied at 60 kg K ha^{-1}. Minimum LAI (0.06) was reported in control plots. The response of LAI (42 DAS) remained same during the second year of study. Leaf area index at 84 DAS was significantly ($p\leq0.05$) affected by K application on growth stages, doses and their interaction during the second year study (Table-6b). Maximum LAI (0.29) was recorded when K was applied in foliar form at booting stage, while minimum (0.20) was obtained at heading stage. Among different K doses, maximum LAI (0.36) was observed when K was applied at 60 kg ha^{-1} and minimum (0.14) in control plots. In interaction, maximum and statistically similar LAI (0.40 and 0.39) was recorded at booting and tillering stages respectively when K was applied at 60 kg ha^{-1}, while minimum (0.12) was obtained in control plots. The data showed similar response of LAI (84 DAS) during 2014-15. The higher LAI might be due to the reduction of stress conditions during the booting as well as tillering stage with foliar application of potassium. Dewdar

(2013) found that soil application along with twice potassium foliar spray at early growth stage significantly increased the number of leaves and total leaf area per plant. Awon *et al*. (2012) also found that foliar application of potassium at wheat growth stages improved drought tolerance of plants and increased the growth parameters. The higher LAI with higher K level might be due to sufficient availability and utilization of potassium during leaves initiation and expansion stages. El-Ashray and Kholy (2005) found that foliar application of K diminished the adverse effects of drought and increased the LAI accordingly.

Table-1. Physico-chemical properties of the experimental site during 2013-2014 and 2014-15 at sowing time.

Parameter	Uniits	2013-14			2014-15		
		Tillering Stage	Booting Stage	Heading Stage	Tillering Stage	Booting Stage	Heading Stage
EC	dsm^{-1}	1.17	1.53	1.60	2.60	2.10	2.24
*p*H	--	7.80	7.70	7.62	8.21	8.21	8.22
Organic matter	%	0.84	0.72	0.80	0.60	0.62	0.62
Extractable P	$mg\ kg^{-1}$	6.40	5.38	5.40	6.30	5.46	5.30
Extractable K	$mg\ kg^{-1}$	203	243	256	203	241	253
Texture class	-	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam

Table-2. Average monthly temperature, humidity and rainfall of the experimental site during 2013-2014 at Agricultural Research Institute, Dera Ismail Khan.

Month	Temperature (°C)		Humidity (%)	Rainfall (mm)
	Minimum	Maximum		
November 2013	10	26	37	02
December 2013	6	22	51	01
January 2014	6	23	53	11
February 2014	7	21	45	38
March 2014	12	24	49	50
April 2014	18	31	44	69
May 2014	22	36	30	8

Source: Arid Zone Research Centre, Pakistan Agriculture Research Council, Dera Ismail Khan, Pakistan.

Table-3. Average monthly temperature, humidity and rainfall of the experimental site during 2014-2015 at Agricultural Research Institute, Dera Ismail Khan.

Month	Temperature (°C)		Humidity (%)	Rainfall (mm)
	Minimum	Maximum		
November 2014	9	27	38	16
December 2014	5	20	51	0
January 2015	5	19	62	28
February 2015	8	22	45	27
March 2015	12	26	58	85
April 2015	13	41	23	38
May 2015	19	42	20	0

Source: Arid Zone Research Centre, Pakistan Agriculture Research Council, Dera Ismail Khan, Pakistan.

Table-4. Weed density, fresh weed biomass, dry weed biomass and relative density of weeds 30 DAS as affected by different doses and stages of K fertilizer application in rainfed wheat during 2013-14.

Treatment	Weed density (m^{-2})	Fresh weed biomass (m^{-2})	Dry weed biomass (m^{-2})	Relative weed density (%)	
				***Convolvulus arvensis* (field bindweed)**	***Alhagi camelorum* (camelthorn)**
Tillering stage	6.94	15.71	3.15	88.89	11.11
Booting stage	5.66	13.06	3.16	100.00	5.55
Heading stage	8.55	16.08	3.68	94.44	0.00
$HSD_{0.05}$	NS	NS	NS	NS	NS
0 kg K ha^{-1}	4.77	13.74	3.38	100.00	0.00
12 kg K ha^{-1}	7.66	13.845	2.99	100.00	0.00
18 kg K ha^{-1}	8.33	17.58	3.61	100.00	0.00
24 kg K ha^{-1}	6.22	13.73	3.02	100.00	0.00
30 kg K ha^{-1}	8.33	17.28	3.89	88.89	11.11
60 kg K ha^{-1}	7.00	13.24	3.08	77.78	22.22
$HSD_{0.05}$	NS	NS	NS	NS	NS
Tillering × 0 kg K ha^{-1}	4.66	14.17	3.17	100.00	0.00
Tillering × 12 kg K ha^{-1}	6.00	12.35	2.41	100.00	0.00
Tillering × 18 kg K ha^{-1}	9.66	23.94	4.12	100.00	0.00
Tillering × 24 kg K ha^{-1}	4.66	10.75	2.00	100.00	0.00
Tillering × 30 kg K ha^{-1}	8.66	19.70	4.38	66.67	33.33
Tillering × 60 kg K ha^{-1}	8.00	13.34	2.81	66.67	33.33
Booting × 0 kg K ha^{-1}	5.66	18.25	4.64	100.00	0.00
Booting × 12 kg K ha^{-1}	7.00	13.61	3.01	100.00	0.00
Booting × 18 kg K ha^{-1}	6.00	11.73	3.11	100.00	0.00
Booting × 24 kg K ha^{-1}	4.33	9.87	2.39	100.00	0.00
Booting × 30 kg K ha^{-1}	5.66	11.80	2.61	100.00	0.00
Booting × 60 kg K ha^{-1}	5.33	13.11	3.21	100.00	0.00
Heading × 0 kg K ha^{-1}	4.00	8.80	2.32	100.00	0.00
Heading × 12 kg K ha^{-1}	10.00	15.58	3.55	100.00	0.00
Heading × 18 kg K ha^{-1}	9.33	17.89	3.62	100.00	0.00
Heading × 24 kg K ha^{-1}	9.66	20.57	4.69	100.00	0.00
Heading × 30 kg K ha^{-1}	10.66	20.34	4.68	100.00	0.00
Heading × 60 kg K ha^{-1}	7.66	13.29	3.24	66.67	33.33
$HSD_{0.05}$	NS	NS	NS	NS	NS

NS = Non-significant

Table-5. Weed density, fresh weed biomass, dry weed biomass and relative density of weeds 60 DAS as affected by different doses and stages of K fertilizer application in rainfed wheat during 2013-14.

Treatment	Weed density (m^{-2})	Fresh weed biomass (m^{-2})	Dry weed biomass (m^{-2})	Relative weed density (%)	
				***Convolvulus arvensis* (field bindweed)**	***Alhagi camelorum* (camelthorn)**
Tillering stage	3.88	4.09	1.17	87.50	12.50
Booting stage	3.72	3.51	1.16	75.00	30.55
Heading stage	4.61	3.75	1.04	100.00	0.32
$HSD_{0.05}$	NS	NS	NS	NS	NS
0 kg K ha^{-1}	3.55	2.66	0.83	100.00	11.11
12 kg K ha^{-1}	4.11	3.54	1.06	88.89	11.11
18 kg K ha^{-1}	4.11	3.83	1.22	86.11	14.54
24 kg K ha^{-1}	4.66	4.02	1.20	86.11	13.88
30 kg K ha^{-1}	4.33	5.12	1.47	75.00	25.00
60 kg K ha^{-1}	3.66	3.52	0.97	88.89	11.11
$HSD_{0.05}$	NS	NS	NS	NS	NS
Tillering × 0 kg K ha^{-1}	3.66	3.17	0.78	100.00	0.00
Tillering × 12 kg K ha^{-1}	3.33	3.11	0.85	100.00	0.00
Tillering × 18 kg K ha^{-1}	4.33	3.89	1.21	100.00	0.00
Tillering × 24 kg K ha^{-1}	3.66	3.54	1.16	100.00	0.00
Tillering × 30 kg K ha^{-1}	4.33	5.90	1.79	58.33	41.66
Tillering × 60 kg K ha^{-1}	4.00	4.94	1.26	66.67	33.33
Booting × 0 kg K ha^{-1}	4.33	2.99	1.04	100.00	33.33
Booting × 12 kg K ha^{-1}	3.66	3.56	1.02	66.67	33.33
Booting × 18 kg K ha^{-1}	4.00	4.49	1.56	58.33	41.66
Booting × 24 kg K ha^{-1}	4.66	3.95	1.22	58.33	41.66
Booting × 30 kg K ha^{-1}	2.33	3.79	1.21	66.67	33.33
Booting × 60 kg K ha^{-1}	3.33	2.27	0.90	100.00	0.00
Heading × 0 kg K ha^{-1}	2.66	1.82	0.68	100.00	0.00
Heading × 12 kg K ha^{-1}	5.33	3.94	1.32	100.00	0.00
Heading × 18 kg K ha^{-1}	4.00	3.12	0.89	100.00	0.00
Heading × 24 kg K ha^{-1}	5.66	4.56	1.24	100.00	0.00
Heading × 30 kg K ha^{-1}	6.33	5.69	1.40	100.00	0.00
Heading × 60 kg K ha^{-1}	3.66	3.35	0.74	100.00	0.00
$HSD_{0.05}$	NS	NS	NS	NS	NS

NS = Non-significant

Table-6a. Leaf area index (42 DAS) as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	0.06 g	0.12 ef	0.13 cde	0.15 b-e	0.16 a-d	0.17 ab	0.13 a	0.06 j	0.12 gh	0.14 ef	0.15 cde	0.16 cd	0.18 ab	0.13 a
Booting	0.06 g	0.12 def	0.13 def	0.12 def	0.16 abc	0.19 a	0.13 a	0.06 j	0.13 fg	0.14 ef	0.14 def	0.16 bc	0.19 a	0.14 a
Heading	0.06 g	0.07 g	0.07 g	0.07 g	0.09 fg	0.12 def	0.08 b	0.06 j	0.07 ij	0.08 i	0.09 i	0.11 h	0.13 fg	0.09 b
Means	0.06 d	0.10 c	0.11 c	0.12 c	0.14 b	0.16 a	-	0.06 e	0.11 d	0.12 c	0.13 c	0.14 b	0.17 a	=
HSD$_{0.05}$	Stages (0.012), K-Doses (0.017), Interaction (0.036)							Stages (0.067), K-Doses (0.076), Interaction (0.017)						

Table-6b. Leaf area duration (84 DAS) as affected by the application of different doses of K on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	0.15 ef	0.17 def	0.21 cde	0.31 ab	0.31 ab	0.39 a	0.26 b	0.15 d	0.17 d	0.20 cd	0.32 ab	0.32 ab	0.38 a	0.26 b
Booting	0.14 ef	0.26 bc	0.29 bc	0.32 ab	0.33 ab	0.40 a	0.29 a	0.14 d	0.26 bc	0.29 b	0.33 ab	0.33 ab	0.40 a	0.29 a
Heading	0.12 f	015 ef	0.14 ef	0.25 bcd	0.27 bc	0.29 bc	0.20 c	0.12 d	0.15 d	0.14 d	0.26 bc	0.27 bc	0.30 b	0.21 c
Means	0.14 d	0.19 c	0.21 c	0.30 b	0.30 b	0.36 a	-	0.14 d	0.19 c	0.21 c	0.30	0.31 b	0.36 a	-
HSD$_{0.05}$	Stages (0.024), K-Doses (0.038), Interaction (0.082)							Stages (0.026), K-Doses (0.036), Interaction (0.080)						

Leaf area duration (42 and 84 DAS)

Significant ($p \leq 0.05$) LAD was noted at 42 DAS during 2013-14 and 2014-15 (Table-7a). Maximum LAD (0.79) was observed when K was applied at booting stage of crop, which was statistically similar to the K applied at tillering stage. Minimum LAD (0.48) was recorded when K was applied at heading stage. Among different K doses, maximum LAD (0.97) was recorded at 60 kg K ha^{-1}. Similarly, minimum LAD (0.35) was obtained in control plots. In interaction, maximum and statistically at par LAD (1.14 and 1.04) was obtained at 60 kg K ha^{-1} applied at booting and tillering stages respectively. Minimum LAD (0.34) was noted in control plots. Similar response was observed, while recording LAD during the study year 2014-15. LAD at 84 DAS indicated significant ($p \leq 0.05$) differences between K application on growth stages, doses and their interaction during both the study years (Table-7b). Maximum LAD (3.52) was recorded when K was applied at booting stage of crop. Minimum LAD (2.44) was obtained in control. Among different K applied doses, maximum LAD (4.43) was found at 60 kg K ha^{-1}. Similarly, minimum LAD (1.64) was recorded in control plots. In interaction, maximum and statistically at par LAD (5.09 and 4.72) was obtained at 60 kg K ha^{-1} applied at booting and tillering stages, respectively. Minimum LAD (1.40) was obtained in control plots. The data showed similar response of recording LAD during the second year study. The higher LAD was probably due to the reduction of stress conditions at booting as well as tillering stages with foliar application of potassium that delayed physiological maturity and increased the crop-growing period. Waraich *et al*. (2011) also found that 2% foliar spray of potassium remarked increased the number of leaves and number of sympodial branches per plant in cotton, which enhanced the vegetative growth and delayed maturity. Maximum LAD with increased levels of potassium might be due to the utilization and translocation of potassium in sufficient quantity to improve many physiological processes. El-Abady *et al*. (2009) noted that potassium foliar application improved many physiological processes and delayed plant senescence.

Table-7a. Leaf area duration (42 DAS) as affected by the application of different doses of K on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	0.34 g	0.70 ef	0.78 cde	0.90 b-e	0.96 a-d	1.04 ab	0.79 a	0.34 j	0.70 gh	0.84 ef	0.90 cde	0.94 cd	1.08 ab	0.80 a
Booting	0.38 g	0.74 def	0.76 c-f	0.74 def	0.98 abc	1.14 a	0.79 a	0.36 j	0.78 fg	0.82 ef	0.86 def	0.98 bc	1.16 a	0.83 a
Heading	0.34 g	0.38 g	0.42 g	0.44 g	0.54 fg	0.74 def	0.48 b	0.36 j	0.44 ij	0.50 i	0.52 i	0.64 h	0.76 fg	0.54 b
Means	0.35 d	0.61 c	0.65 c	0.69 c	0.83 b	0.97 a		0.35 e	0.64 d	0.72 c	0.76 c	0.85 b	1.0 a	
$HSD_{0.05}$	Stages (0.051), K-Doses (0.104), Interaction (0.226)							Stages (0.040), K-Doses (0.046), Interaction (0.099)						

Table-7b. Leaf area duration (84 DAS) as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	1.84 ef	2.04 ef	2.48 de	3.76 bc	3.76 bc	4.72 ab	3.10 b	1.76 d	2.04 d	2.40 cd	3.88 ab	3.84 ab	4.60 a	3.09 b
Booting	1.68 ef	3.08 cd	3.48 c	3.84 bc	3.92 bc	5.09 a	3.52 a	1.68 d	3.12 bc	3.48 b	3.92. ab	3.96 ab	4.80 a	3.49 a
Heading	1.40 f	1.76 ef	1.72 ef	3.04 cd	3.28 cd	3.48 c	2.44 c	1.44 d	1.76 d	1.72 d	3.08 bc	3.24 bc	3.56 b	2.47 c
Means	1.64 d	2.29 c	2.56 c	3.55 b	3.65 b	4.43 a	-	1.63 d	2.31 c	2.53 c	3.63 b	3.68 b	4.32 a	-
$HSD_{0.05}$	Stages (0.197), K-Doses (0.467), Interaction (1.011)							Stages (0.312), K-Doses (0.439), Interaction (0.950)						

Crop growth rate (CGR) (g m^{-2} day^{-1})

Significant ($p \leq 0.05$) results were noted regarding effect of K application on growth stages, doses and their interaction on wheat during both the study years (Table-8). During the first year 2013-14, maximum CGR (3.99) was noted in foliar application of K at booting stage in comparison to CGR recorded at tillering and heading stages. The year 2014-15 also showed similar response of increased CGR in foliar application at booting stage. It was probably due to the reason that potassium application in foliar form at booting stage improves many physiological growth processes and hence accelerates the crop growth rate. Foliar application of potassium at all growth stages of wheat mitigates the adverse conditions of stress and hence increased the crop growth rate (Aown *et al*., 2012). During the first year research, the CGR increased with increasing levels of potassium. The maximum CGR (5.13) was recorded at 60 kg K ha^{-1}, while minimum (2.90) in control plots where no potassium was applied. The data showed similar response of increased CGR with the increasing K levels during the year of study. It was due to higher and prolonged photosynthetic activity as K improves many physiological processes and delays plant leaves senescence. Abou-El-Defan *et al*. (2005) also found that application of potassium improved the physiological processes as well as crop growth. In interaction, maximum and statistically at par CGR (6.25 and 5.30) was obtained at 60 and 30 kg K ha^{-1} in foliar applied potassium at booting stage. Similarly, minimum CGR (1.76) was recorded in control plots. Similar response of CGR was found during the second year study. This might be attributed that foliar applied K at booting stage improved physiological processes of the plant and hence increased the CGR accordingly. These results are in complete analogy with those of El-Ashray and Kholy (2005) who reported that foliar application of K reduces the negative effects of drought on growth and in turn increases the yield per plant.

Net assimilation rate (g m^{-2} day^{-1})

The data showed that K application on growth stages, doses and their interaction significantly affected net assimilation rate during 2013-14 (Table-9). Maximum and statistically similar NAR (0.89 and 0.83) was recorded at heading and booting stages, respectively. While minimum NAR (0.76) was recorded at tillering stage. It might be due to the reduction of adverse effect of moisture stress at heading as well as booting stages. Abou-El-Defan *et al*. (2005) noted that application of potassium improved the physiological growth processes as well as crop growth and hence NAR value. The year 2014-15 also showed similar response of increased NAR in foliar application at heading stage. Among various K levels, higher NAR (0.97) was noted in the plants treated with 60 kg K ha^{-1} followed by 0.87 with 12 kg K ha^{-1}, which were statistically similar to each other whereas lowest NAR (0.66) was noted in control. The higher NAR was due to the application of potassium, which mitigates the stress condition and prolong the crop growth period (El-Ashray and Kholy, 2005). During the second year research, the NAR remained non-significant among different K levels. The interaction of various growth stages and K levels produced significantly higher NAR (1.02) at booting stage with 60 kg K ha^{-1} followed by 30 kg ha^{-1} at the same stage. The NAR (0.97) recorded at heading stage with 60 kg ha^{-1} was also statistically at par with these two treatments. Minimum (0.59) NAR was recorded in control where no potassium fertilizer was applied. The year 2014-15 also showed almost similar response of NAR at different stages.

Table-8. Crop growth rate (g m^{-2} day^{-1}) as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	1.76 e	2.44 de	3.14 de	2.92 de	3.07 de	4.89 abc	3.07 b	1.89 f	2.45 ef	3.17 def	2.96 def	3.06 def	4.92 abc	3.08 b
Booting	1.97 e	3.25 cde	3.29 cde	4.11 bcd	5.30 ab	6.25 a	3.99 a	1.79 f	3.20 c-f	3.29 c-f	4.07 b-e	5.31 ab	6.32 a	3.99 a
Heading	1.97 e	2.51 de	3.28 cde	3.33 cde	3.81 bcd	4.24 bcd	3.19 b	1.89 f	2.51 ef	3.33 c-f	3.44 c-f	3.89 b-e	4.57 a-d	3.27 b
Means	2.90 d	2.73 c	3.24 c	3.45 bc	4.06 b	5.13 a	-	1.86 d	2.72 c	3.26 c	3.49 bc	4.09 b	5.27 a	-
$HSD_{0.05}$	Stages (0.526), K-Doses (0.807), Interaction (1.746)							Stages (0.542), K-Doses (0.0.770), Interaction (1.667)						

Table-9. Net assimilation rate (g m^{-2} day^{-1}) as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	0.59 c	0.89 ab	0.95 a	0.61 c	0.59 c	0.92 a	0.76 b	0.87 ab	0.76 b	0.82 ab	0.57 b	0.58 b	0.79 ab	0.73 b
Booting	0.63 c	0.82 abc	0.65 bc	0.87 ab	0.99a	1.02 a	0.83 ab	0.83 ab	0.74 b	0.70 b	0.80 ab	0.97ab	0.97 ab	0.84 b
Heading	0.77 abc	0.92 a	0.81 abc	0.90 ab	0.95a	0.97 a	0.89 a	0.94 ab	1.06 ab	1.31 a	0.96 ab	0.96ab	0.99 ab	1.03 a
Means	0.66 c	0.88 ab	0.80 b	0.79 b	0.84b	0.97 a	-	0.88 NS	0.85	0.94	0.77	0.84	0.92	-
$HSD_{0.05}$	Stages (0.090), K-Doses (0.106), Interaction (0.229)							Stages (0.183), K-Doses (NS), Interaction (0.510)						
NS= Non-significant														

Net photosynthesis rate (μ mol m^{-2} sec^{-1})

The data showed significant ($p \leq 0.05$) results regarding K application on growth stages, doses and their interaction at 63 days after sowing during 2013-14 and 2014-15 (Table-10a). Maximum pyridine nucleotide (Pn) (14.1) was recorded when K was applied at booting stage of crop, while minimum (12.5) was found when K was applied at tillering stage. Among different K doses, maximum Pn (16.1) was recorded at 60 kg K $ha^{-1}$and minimum (9.3) in control plots. In interaction, maximum Pn (17.1) was obtained at 60 kg K ha^{-1} applied at booting stage of crop. Minimum Pn (9.1) was noted in control plots. The trend of recording net photosynthesis rate was the same during the year 2014-15. Net photosynthesis rate at 126 DAS indicated significant ($p \leq 0.05$) differences between K application on growth stages, doses and their interaction during both the years (Table 10b). Maximum Pn (2.8) was obtained when K was applied at booting stage of crop. Minimum Pn value (2.3) was recorded in control. Among different doses, maximum Pn (5.0) was obtained at 60 kg K ha^{-1} and minimum (0.9) in control plots where no potassium was applied. In interaction, maximum Pn (5.6) was found at 60 kg K ha^{-1} applied in booting stage of crop. Minimum Pn (0.8) was obtained in control plots. The trend of recording net photosynthesis rate was almost the same during the year 2014-15. The higher Pn was probably due to the reduction of stress conditions at booting with foliar application of potassium that delayed physiological maturity and increased the net photosynthesis rate. Xiabong *et al.* (2004) and Hossain *et al.* (2010) reported that higher levels of potassium increased the photosynthesis process acco rdingly.

Grain yield (kg ha^{-1})

The grain yield was significantly affected by foliar application of K on critical growth stages, doses and interaction (Table-11). During the year 2013-14, maximum grain yield (3066 kg ha^{-1}) was noted at booting stage as compared to tillering and heading stages (2534 and 2753 kg ha^{-1}). It might be due to the reason that potassium plays a leading role in the stomatal opening and closing of plants under unfavorable stress condition, which increased the grain yield accordingly (Foyer *et al*., 2002). These results are also in complete analogy with the findings of Gul *et al*. (2011). Among different K applied doses, maximum grain yield (4057 kg ha^{-1}) was obtained when K was applied @ 60 kg ha^{-1}, while minimum (1580 kg ha^{-1}) was in control. The interaction of stages and doses showed maximum grain yield (4360 kg ha^{-1}) when 60 kg K ha^{-1} was applied at booting stage, which was statistically at par with grain yield (3990 kg ha^{-1}) recorded at heading stage with the same dose of potassium. Grain yield increased with the increasing levels of K probably due to the reason that higher levels of potassium boost up many physiological and growth processes i.e. increases root growth and facilitates the translocation of nutrients and photo-assimilates (Tiwari, 2002.). Khan *et al*. (2014) also found the same results at maximum K doses. The trend of results remained the same during the second year study.

Table-10a. Net photosynthesis rate (µ mol m^{-2} sec^{-1}) 63 DAS as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	9.1 j	11.1 i	11.8 gh	12.7 f	14.5 d	15.6 c	12.5 c	8.9 n	10.9 m	11.7 k	12.2 ij	4.3 f	15.2 d	12.2 c
Booting	9.4 j	12.5 f	13.3 e	15.7 c	16.4 b	17.1 a	14.1 a	9.0 n	12.7 h	13.3 g	15.3 d	16.4 b	16.9 a	13.9 a
Heading	9.3 j	11.7 h	12.0 g	12.4 f	14.8 d	15.6 c	12.6 b	8.9 n	11.3 l	11.9 jk	12.3 i	14.8 e	15.7 c	12.5 b
Means	9.3 f	11.8 e	12.4 d	13.6 c	15.2 b	16.1 a	-	9.0 f	11.6 e	12.3 d	13.3 c	15.2 b	15.9 a	-
$HSD_{0.05}$	Stages (0.14), K-Doses (0.12), Interaction (0.26)							Stages (0.12), K-Doses (0.09), Interaction (0.19)						

Table-10b. Net photosynthesis rate (µ mol m^{-2} sec^{-1}) 126 DAS as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	0.8 k	1.2 ij	1.5 fgh	2.3 e	3.3 d	4.6 b	2.3 c	0.7 k	1.2 j	1.3 j	2.4 g	3.4 e	4.7 b	2.3 c
Booting	0.9 jk	1.5 ghi	1.7 f	3.3 d	3.7 c	5.6 a	2.8 a	0.9 k	1.7 hi	1.8 h	3.6 d	3.8 c	5.5 a	2.9 a
Heading	0.9 k	1.3 hi	1.6 fg	2.6 e	3.5 cd	4.9 b	2.4 b	0.9 k	1.3 j	1.6 i	2.6 f	3.6	4.9 b	2.5 b
Means	0.9 f	1.3 e	1.6 d	2.7 c	3.5 b	5.0 a	-	0.8 f	1.4 e	1.5 d	2.9 c	3.6 b	5.0 a	-
$HSD_{0.05}$	Stages (0.13), K-Doses (0.11), Interaction (0.25)							Stages (0.10), K-Doses (0.10), Interaction (0.14)						

Table-11. Grain yield (kg ha^{-1}) as affected by different K application on growth stages and doses in rainfed wheat production during 2013-14 and 2014-15.

K application Stages	2013-14							2014-15						
	Potassium doses (kg ha^{-1})						Means	Potassium doses (kg ha^{-1})						Means
	(0)	(12)	(18)	(24)	(30)	(60)		(0)	(12)	(18)	(24)	(30)	(60)	
Tillering	1560 j	2043 g-j	2430 e-h	2417 e-i	2937 def	3817 abc	2534 b	1668 ij	2095 hij	2455 gh	2601 fgh	2945 d-g	3800 abc	2594 c
Booting	1587 ij	2580 efg	3177 b-e	3210 b-e	3483 bcd	4360 a	3066 a	1633 j	2713 e-h	3261 c-f	3320 b-e	3594 bcd	4413 a	3156 a
Heading	1593 hij	2150 f-j	2223 f-j	3133 cde	3427 bcd	3990 ab	2753 b	1673 ij	2203 hij	2330 ghi	3165 c-f	3520 bcd	3991 ab	2813 b
Means	1580 e	2258 d	2610 cd	2920 bc	3282 b	4057 a		1658 f	2337 e	2682 d	3029 c	3353 b	4068 a	
HSD$_{0.05}$	Stages (223.34), K-Doses (382.58), Interaction (828.13)							Stages (153.90), K-Doses (315.95), Interaction (683.90)						

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