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Response of Wheat Crop to Potassium Fertilization Under Rain-fed Conditions in Semi-arid Regions

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Abstract

Wheat is regarded as one of the major field crops that are mainly grown under rain-fed conditions in Jordan. However, wheat productivity is relatively lower than the world average. This is primarily due to the prevailing drought conditions as a result of poor distribution and low amounts of rainfall. Research studies showed that K can markedly improve wheat yield and quality under water deficit conditions. The objective of the current study was to investigate the effect of soil-applied mineral potassium (K) fertilizer on the yield and growth parameters of two local durum wheat varieties under rain-fed conditions in Jordan. And to determine the rate of K needed to obtain the optimum wheat yield. Two field trials were conducted under rain-fed conditions in two locations in Jordan. Two local durum wheat varieties were grown during two successive growing seasons. Five different rates of K were applied at sowing time. A randomized complete block design with four replications was followed. The results showed that soil K application exhibited a significant effect on wheat crop grain and biological yields of both varieties at the two locations. However, an increasing trend in plant height, harvest index, and thousand-grain weight with increasing K application rate was noticed. Potassium application to soil can alleviate the adverse effects of drought stress on the wheat crop by improving growth and yield attributes.

Keywords: chlorophyll, drought stress, harvest index, grain yield

1. Introduction

Wheat crop is the third most-produced cereal commodity globally after maize and rice. It is a primary staple food due to its importance for world food security (Gul et al., 2011; Samad et al., 2014; Gu et al., 2021), with a world annual production of 776.7 million tons in 2020/2021 (FAO, 2022). Wheat is an important source of the most calories and proteins consumed by people worldwide (Chaves, 2013). Bread wheat (*Triticum aestivum* L.) accounts for approximately 95% of the wheat produced globally, with most of the rest being durum wheat (*Triticum durum* L.) (Kobata et al., 2018). Improving wheat productivity is a national goal to meet the demands of high rates of population growth (Ahmed et al., 2011).

Plants exposed to environmental stress conditions, like drought, suffer from oxidative damage catalyzed by reactive oxygen species (ROS). ROS are known to be primarily responsible for the impairment of cellular function and growth depression under stress conditions (Cakmak, 2005). Drought is a common abiotic stress and is regarded as the most important challenge resulting from the adverse effects of climate change which primarily occurs in semi-arid regions. It is considered a major threat that can reduce plant growth and yield (Aown, et al. 2012). Fertilizers application can enhance the productivity of crops which in turn will be more efficient in their water use. However, the low soil moisture content may reduce the availability of nutrients (Warder et al., 1963).

The nutrient status of plants has a major role in their adaptation to environmental stress. In this context, potassium (K) plays a key role in improving plant resistance and survival under adverse environmental situations (Jiang et al., 2018). It is one of the major essential nutrients required for the normal growth and development of plants (Khan et al. 2007). It is involved in many physiological and biochemical processes like photosynthesis, translocation of assimilate into sink organs, regulation of turgor pressure (osmoregulation), nutrient and water transport and uptake, carbohydrate metabolism, energy transfer, cation-anion balance, enzyme activation, and protein synthesis that have a significant effect on wheat productivity (Cakmak, 2005; Ali et al. 2019; Hefny 2021; Tesfaye et al., 2021). Besides improving plant resistance against abiotic and biotic stresses (Qui, et al., 2014; Dar et al., 2021), K is known as a quality nutrient because it is involved in metabolic processes that enhance crop quality (Ali et al. 2019). Nevertheless, K has been given less attention than nitrogen (N) and phosphorus (P) with respect to increasing cereal production because K has a less pronounced effect on increasing cereal production, especially in soils with high levels of K (Qui, et al., 2014).

The reductions in grain yield and quality are the most important challenges of wheat production under drought stress conditions in arid and semi-arid regions. However, K application can induce enhancements in wheat yield and quality under deficit water situations (Sedri et al. 2022). Adequate amounts of K, as a foliar application at 60 mmol K/l in the form of potassium chloride (KCl) at the flowering stage, resulted in increases in the wheat yield and crude protein content (Gu et al. 2021). Improvements in the growth and yield of wheat crop with the application of K have been mentioned in earlier reports (Arif et al., 2017; Mohamed, 2017).

In Jordan, which has a semi-arid typical Mediterranean climate, wheat crop is regarded as one of the major field crops that is mainly grown under rain-fed conditions. It is cultivated in areas receiving more than 250 mm of annual rainfall. However, the productivity of cereal crops is relatively lower than the world average. This is primarily due to the prevailing drought conditions as a result of low and poor distribution of rainfall, inherited low fertility, absence of crop rotation, low organic matter, and minimal or no use of fertilizers (Khatari et al., 2011). The uneven distribution of precipitation is the main reason for the yield drop due to instabilities in water and nutrient uptake (Renata and Gorski, 2014). The negative impact of climate change in the region is expected to further aggravate the drought stress.

Jordan has a very shortage of wheat production and is very far from self-sufficiency in this respect. The average wheat production in 2019 was 26,361 tons, harvested area of 11,018 ha, and a yield of 2.39 ton/ha (FAOSTAT, 2021). Meanwhile, the estimated amount of wheat imported in 2018 was 900 thousand tons (Khalaf et al., 2021).

Recent studies have shown that K fertilizer application has markedly improved wheat yield and quality (Jiang et al., 2018; Ali et al., 2019; Tesfaye et al., 2021). However, local research studies on optimal K application rates for wheat crop production improvement are very limited and there is a lack of adequate knowledge regarding this vital issue. Therefore, the response of some local wheat varieties to soil-applied mineral K fertilizers principally in terms of grain yield was investigated in some rain-fed regions in Jordan.

Determining the optimum level of potassium application for wheat crops in Jordan would help improve crop productivity and thus enhance the country's food security.

2. Materials and Methods

2.1 Study Areas and Experimental Sites

Two field trials were conducted at two Agricultural Research Stations of the National Agricultural Research Center (NARC) in rain-fed locations in Jordan for two successive growing seasons (2019/2020 and 2020/2021). The first experimental site was at Mushaqar (31^{o} 45' 16.3" N, 035^{o} 48' 01.5" E, 796.3 m above sea level, and a mean annual rainfall of 305 mm). The seasonal rainfalls during the two seasons were 355.3 and 291.7 mm, respectively. Meanwhile, the second experimental site was at Maru (32^{o} 35' 04.7" N, 035^{o} 54' 00.3" E, 589 m above sea level with a long-term average rainfall of 400 mm). The seasonal rainfalls during the two growing seasons were 553.5 and 367.0 mm, respectively. The soils at both locations are classified as chromoxeret (Vertisols).

2.2 Plant Materials

Two local wheat (*Triticum durum* L.) varieties were investigated; the first one was Cham 1 which was tested at the Mushaqar site; while the second one was Um Qais which was tested at the Maru site. They were seeded at 120 (by mechanical planter), and 130 (manually) kg/ha rates, respectively, according to the common practices followed by farmers in those regions.

2.3 Cultural Practices

The land was cultivated and the seedbed was well prepared for the two experimental sites. The plot area, at the Mushaqar site, was 9.9 m^2 (1.5 m in width x 6.6 m in length; 6 rows and 25 cm apart), with separation strips between plots and between blocks of 2.0 m each. The length and width of the experimental site were 41.0 m and

12.0 m, respectively, with a total area of 492.0 m^2. Meanwhile, the plot area at the Maru site was 10.0 m^2 (2.0 m in width x 5.0 m in length; 6 rows and 33 cm apart), with separation strips between plots and between blocks of 2.0 m each. The length and width of the experimental site were 33.0 m and 14.0 m, respectively, with a total area of 462.0 m^2. In the first growing season (2019/2020), sowing was carried out at Maru and Mushaqar experimental sites on 03, December 2019, and 04, December 2019, respectively. Meanwhile, in the second season (2020/2021), sowing was carried out at Maru and Mushaqar sites on December 8th, 2020, and December 9th, 2020, respectively. In both growing seasons**,** di ammonium phosphate (DAP), ($(NH_4)_2HPO_4$, 18-46-0) and urea ($CO(NH_2)_2$, 46-0-0) were applied at rates of 100 and 50 kg/ha, respectively. The total amount of DAP and half the quantity of urea were broadcasted and incorporated into the soil at the time of soil preparation and pre-planting (a basal dose). While the remaining half dose of urea was applied at tillering stage. Micronutrients in a chelating form (Fe (4%), Zn (4.0), Mn (3.0%), Cu(0.5%), B(1.5%), Mo(0.05%, Mg(1.3%), and S(1.3%)) was applied at pre-planting with the other fertilizers at 10.0 kg/ha rates, as recommended by Melash et al. (2019). Weeds were controlled both manually and chemically using 2,4-Dichlorophenoxyacetic acid (2,4-D) and Antelope Clodinafop-propagyl.

2.4 Treatments

Five different rates of K (as sulfate of potash, SOP, K_2SO_4, 0-0-50) were applied at sowing time, in both seasons: T1= Control, 0 kg K_2O/ha; T2 = 20 kg K_2O/ha; T3 = 40 kg K_2O/ha; T4 = 60 kg K_2O/ha; and T5 = 80 kg K_2O/ha.

2.5 Experimental Design and Statistical Analysis

Randomized complete block design (RCBD) with 4 replications was followed, and analysis of variance (ANOVA) was conducted using Statistical Analysis Software (SAS) version 9.0 for Windows (SAS Institute Inc. 2002); and whenever treatment effects were significant, means separation was made using the least significant difference (LSD) test at the 5% level of probability.

2.6 Soil Chemical and Physical Analysis

A composite surface soil sample (0-30 cm) before sowing was collected from each of the 4 blocks of each experimental site for some physical and chemical analysis. The samples were air-dried, crushed, and passed through a 2 mm sieve, and then analyzed. Paste extract was subjected to the analysis of soil pH and salinity according to Bower and Wilcox (1965), organic matter according to Allison (1965), calcium carbonate (calcimeter method) according to Allison and Moodie (1965), total N (Kjeldahl method) according to Bremner (1965), available P (using spectrophotometer) according to Olsen and Dean (1965), available K (using flame photometer) according to Pratt (1965), and soil texture (hydrometer method) according to Day (1965).

2.7 Chlorophyll Measurement

Total chlorophyll content was determined non-destructively using a portable hand-held chlorophyll meter (SPAD-502 Plus). Chlorophyll readings for five randomly selected plants from each plot were determined at the heading stage of the crop and averaged. The readings represented by the SPAD values were taken by putting the flag leaf on the scanner of the meter and hold for a while (Ali et al., 2019).

2.8 Plant Harvesting and Yield Measurements

Plant harvesting was performed after complete plant maturity (when the peduncle turns golden yellow with a complete loss of the green color); according to Melash et al. (2019). In the first season, harvesting was made on July 01, 2020, and July 07, 2020, at Mushaqar and Maru sites, respectively. Meanwhile, in the second season, harvesting was performed on July 01, 2021, and July 07 2021 at Maru and Mushaqar sites, respectively. Plants of 1 m^2 from 3 random locations from each plot were harvested using a square quadrate of 1 m^2 area and separated into grains and straws. Thousand-grain weight (TGW), grain yield (GY), straw yield (SY), and biological yield (BY) were recorded. The harvest index (HI) was calculated as (GY/BY) (Kobata et al., 2018). Ten plants were selected randomly from each plot to record the plant height (cm) using a measuring rod from the soil surface to the upper part of the spike without awns and then averaged (Hussain et al., 2018). The average moisture contents of grains and straws at harvest were 6.0% and 7.0%, respectively. Threshing was performed by a machine in the separation of straw and grain (Abro et al., 2022).

3. Results

3.1 Mushagar Agricultural Station

3.1.1 Physiochemical Properties of Soil

The soil of the experimental site at Mushaqar Station in the first growing season (2019/2020) was calcareous, and clay in texture (13% sand, 37% silt, and 50% clay) with an average pH of 7.7 ±0.1 and salinity of

0.891±0.182 dS/m. The average values of soil total N, available P, K, calcium carbonate, and organic matter content were 0.100±0.021%, 13.7±2.1 mg/kg, 450±5.8 mg/kg, 18.4±2.5%, and 0.99±0.05%, respectively. The soil of the experimental site in the second growing season (2020/2021) was also calcareous, and clay in texture (13.5% sand, 32.2% silt, and 54.3% clay) with an average pH of 7.6±0.2 and salinity of 1.08±0.19 dS/m. The average values of soil total N, available P, K, calcium carbonate, and organic matter contents were 0.07±0.01%, 13.3±0.87 mg/kg, 683±61 mg/kg, 18.4±2.5%, and 0.62±0.17%, respectively.

3.1.2 Effect of Potassium on Crop Yield and Growth Parameters

Soil K application showed a significant effect on wheat crop yields and harvest index (HI) of Cham1 variety at the Mushagar Agricultural Station experimental site during the first growing season (2019/2020), as shown in Table 1. The results revealed that increasing the K application rate induced significant increases in the crop biological, grain, and straw yields. Where the highest yield values (1549, 597, and 952 g/m^2, respectively) were recorded at the highest K application rate of 80 kg K_2O/ha (T5). Meanwhile, the lowest respective yield values (1395.00, 540.10, and 854.90 g/m^2) were obtained at the control (T1, no K addition). The highest rate of K (T5) recorded 11.06, 10.58, and 11.36% higher biological, grain, and straw yields, respectively, than those gained at the control treatment. However, there were no significant differences in this respect among the treatments of T3, T4, and T5, indicating that the optimum K level was attained at the application rate of 40 kg K_2O/ha (T3) with biological, grain, and straw yields of 1530.58, 581.90, and 948.65 g/m^2, respectively; more K additions beyond that rate induced no significant increases in crop yield. The increments in biological, grain and straw yields at T3 represented 9.71, 7.74, and 10.99%, respectively, higher than those obtained at the control. Also, the highest significant harvest index (HI) value was recorded at the T5 (46.73%), though no significant differences in HI values were reported among T3 (41.98%), T4 (41.65%), and T5 application rates. The control treatment (T1) recorded the lowest significant HI value (35.33%) but didn’t significantly differ from that registered at T2 (37.85%). On the other hand, no significant effect for K application was noticed on the plant height, TGW, and chlorophyll content (represented by SPAD value) at the heading stage. However, an increasing tendency for plant height and TGW with increasing K application rate was noticed. The highest values of plant height and TGW were recorded at T5 (102.50 cm and 36.35 g, respectively), whereas, the lowest values were obtained at the control treatment (98.82 cm and 36.03 g, respectively). The chlorophyll content ranged from 43.03 at the control treatment to 54.33 at T5 treatment. Likewise, the soil K application rate showed a significant effect on wheat crop yields of Cham1 variety during the second growing season (2020/2021), as presented in Table 1. The results revealed that increasing the K application rate induced significant increases in the crop biological and grain yields. The highest significant values of these yield parameters (339.60 and 20.025 g/m^2, respectively) were recorded at the highest K application rate of 80 kg K_2O/ha (T5). Meanwhile, the lowest respective significant yield values (304.75, and 7.825 g/m^2) were obtained at the control (T1). The highest application rate of K (T5) recorded 10.3 and 60.9% higher biological and grain yields, respectively than those gained at the control treatment. However, there were no significant differences in the biological and grain yields among the treatments of T3, T4, and T5, indicating that the optimum K level was achieved, also, at the application rate of 40 kg K_2O/ha (T3) with biological and grain yields of 316.50 and 15.425 g/m^2, respectively; more K additions beyond that rate induces no significant increases in crop yield. The increments in biological and grain yields at T3 represented 3.7 and 49.2%, respectively, higher than those gained at the control. No significant effect for the K rate was detected on the plant straw yield, though an increasing trend was noticed, with the highest and lowest values obtained at T5 and T2 (319.55 and 296.33 g/m^2, respectively). Similarly, no significant effect for K application rate was detected on the plant height, TGW, HI, and chlorophyll content. However, there was an obvious trend for plant height, HI, and TGW to increase with an increasing K application rate. The highest values of plant height, HI, and TGW occurred at T5 (72.80 cm, 5.95%, and 33.94 g, respectively). The respective lowest values were obtained at T1 (68.00 cm, 2.55%, and 33.22 g). Meanwhile, the chlorophyll content varied between 45.13 (at T3) and 51.50 (at the control treatment).

Table 1. Effect of different levels of K on growth and yield parameters and chlorophyll reading of wheat crop (Cham 1 variety) under the rain-fed condition at Mushagar Agricultural Station in the 2019/2020 and 2020/2021 growing seasons

Treatment K level	Plant height	Biological Yield	Grain Yield	Straw Yield	HI	TGW	Chlorophyll reading @ heading
kg K_2O/ha	cm	g/m^2			%	g	SPAD Unit
2019/2020							
T1 = Control,0	98.82a	1395.00c	540.10b	854.90b	35.325c	36.0250a	43.025a
T2 = 20	99.80a	1466.75b	547.05b	919.70ab	37.850bc	36.0750a	51.450a
T3 = 40	100.25a	1530.58a	581.90a	948.65a	41.975ab	36.1000a	45.125a
T4 = 60	101.67a	1542.95a	583.65a	959.33a	41.650ab	36.1750a	50.375a
T5 = 80	102.50a	1549.25a	597.25a	952.03a	46.725a	36.3500a	54.325a
Mean	100.6	1496.905	569.99	926.92	40.705	36.14500	48.86
LSD$_{0.05}$	6.15	50.575	24.347	67.839	5.1581	0.3301	13.599
Significance level	Ns	*	*	*	*	Ns	Ns
2020/2021							
T1 = Control,0	68.000a	304.75b	7.825b	296.93a	2.550b	33.2200a	51.500a
T2 = 20	71.800a	309.00b	12.675ab	296.33a	4.150ab	33.6150a	50.550a
T3 = 40	71.850a	316.50ab	15.425ab	301.08a	4.875ab	33.7975a	45.125a
T4 = 60	72.500a	336.68a	18.350a	318.33a	5.425a	33.8150a	48.475a
T5 = 80	72.800a	339.60a	20.025a	319.55a	5.950a	33.9375a	49.325a
Mean	71.39	321.30	14.86	306.44	4.59	33.67	48.99
LSD$_{0.05}$	7.0812	24.028	7.6887	26.043	2.395	1.5009	7.8115
Significance level	Ns	*	*	Ns	Ns	Ns	Ns

Ns: Not significant, *Significant at $p \leq .05$. Within each column, means with different letter(s) are significantly different according to LSD test at 0.05 level of probability.

3.2 Maru Agricultural Station

3.2.1 Physiochemical Properties of Soil

Meanwhile, the soil of the experimental site at Maru Station in the first growing season was slightly calcareous, and clay in texture (13% sand, 32% silt, and 55% clay) with an average pH of 7.7±0.1 and salinity of 0.651±0.066 dS/m. The average values of soil total N, available P, K, calcium carbonate, and organic matter content were 0.130±0.017%, 8.5±1.3 mg/kg, 361±20 mg/kg, 4.5±0.7%, and 1.28±0.22%, respectively. The soil of the experimental site in the second growing season was also slightly calcareous, and clay in texture (9.2% sand, 33.2% silt, and 57.6% clay) with an average pH of 7.7±0.1 and salinity of 0.67±0.06 dS/m. The average values of soil total N, available P, K, calcium carbonate, and organic matter contents were 0.079±0.005%, 15.40±2.31 mg/kg, 424±9.39 mg/kg, 3.55±0.54%, and 1.08±0.16%, respectively.

3.2.2 Effect of Potassium on Crop Yield and Growth Parameters

A significant effect of K application rate on the yield of wheat crop (Um Qais variety), at the Maru Agri. Station experimental site, was also distinguished during the first growing season (2019/2020), as presented in Table 2. The highest values of biological, grain, and straw yields were obtained at the application rate of 80 kg K_2O/ha (T5): 1097.68, 329.79, and 767.90 g/m^2, respectively. The increments in these yield values were 35.67, 42.55, and 32.91%, higher than those obtained at the control treatment (809.08, 231.35, and 577.78 g/m^2, respectively). However, there were no significant differences in that respect between the treatments T4 and T5, indicating that the optimum K rate was at the application rate of 60 kg K_2O/ha (T4) with biological, grain, and straw yields of 941.80, 289.69, and 652.13 g/m^2, respectively; beyond which no significant increase in crop yield is expected. The increments in biological, grain and straw yields at T4 represented 16.40, 25.22, and 12.87%, respectively, as compared with those obtained at the control. No significant effect for K application was remarked on plant height, HI, TGW, and chlorophyll content. However, plant height, HI, and TGW tended to increase as the K application rate increased. The highest plant height and TGW were recorded at T5 (111.10 cm and 43.40 g, respectively). Meanwhile, the lowest values were obtained at T1 (107.67 cm and 42.22 g, respectively). The values of the HI ranged from 28.92 (at T1) to 31.97% (at T2). Meanwhile, chlorophyll content varied from 45.65 (T5) to 51.67 (T3).

In the same way, the K application rate also demonstrated a significant effect on the wheat crop (Um Qais variety) biological and grain yields during the second growing season (2020/2021), as shown in Table 2. The highest values of biological, grain, and straw yields were recorded at the application rate of 80 kg K_2O/ha (T5): 776.83, 243.75, and 533.08 g/m^2, respectively. The increments in these yield values were 23.88, 34.04, and 19.72%, as compared with those obtained at the control treatment (627.08, 181.85, and 445.28 g/m^2, respectively). However, there were no significant differences in that regard among the treatments T3, T4, and T5, indicating that the optimum K rate was at the application rate of 40 kg K_2O/ha (T3) with biological, grain, and straw yields of 667.93, 212.10, and 455.83 g/m^2, respectively; beyond which no significant increase in crop yield is expected. These increases in biological and grain yields at T3 represented 6.1, 14.3, and 2.4%, respectively, as compared with those recorded at the control. No significant effect for K application was noted on plant height, HI, TGW, and chlorophyll content. However, there was also a clear tendency for the plant height, HI, and TGW to increase with an increasing K application rate. The highest plant height and TGW were reported at T5 (89.05 cm and 33.80 g, respectively), while the lowest values were recorded at T1 (84.10 cm and 31.97 g, respectively). Meanwhile, HI values ranged from 29.17 (at T1) to 31.80% (at T3 and T4), and chlorophyll content varied from 48.40 (at T2) to 49.35 (at T5).

Table 2. Effect of different levels of K on growth and yield parameters and chlorophyll reading of wheat crop (Um Qais variety) under the rain-fed condition at Maru Agricultural Station in the 2019/2020 and 2020/2021 growing seasons

Treatment K level	Plant height	Biological yield	Grain yield	Straw yield	HI	TGW	Chlorophyll reading @ heading
kg K_2O/ha	cm	g/m^2			%	g	SPAD Unit
			2019/2020				
T1 = Control, 0	107.67a	809.08c	231.35c	577.78b	28.92a	42.22a	48.87a
T2 = 20	108.17a	851.90bc	271.58bc	580.30b	31.97a	42.66a	48.07a
T3 = 40	108.60a	906.75bc	274.48b	632.28b	30.35a	42.70a	51.67a
T4 = 60	110.40a	941.80b	289.69ab	652.13ab	30.80a	43.08a	46.07a
T5 = 80	111.10a	1097.68a	329.79a	767.90a	30.40a	43.40a	45.65a
Mean	109.19	921.44	279.37	642.07	30.49	42.81	48.07
$LSD_{0.05}$	4.08	131.2	40.46	124	5.33	2.88	6.66
Significance level	Ns	*	*	*	Ns	Ns	Ns
			2020/2021				
T1 = Control, 0	84.100b	627.08b	181.85c	445.28b	29.17a	31.97a	48.90a
T2 = 20	86.600ab	654.28b	196.65bc	457.58ab	29.77a	32.77a	48.40a
T3 = 40	88.900a	667.93b	212.10abc	455.83ab	31.80a	32.82a	49.30a
T4 = 60	88.900a	713.25ab	228.33ab	484.93ab	31.80a	32.90a	49.02a
T5 = 80	89.050a	776.83a	243.75a	533.08a	31.17a	33.80a	49.35a
Mean	87.51000	687.8700	212.5350	475.3350	30.74	32.85	48.99
$LSD_{0.05}$	4.78	100.4	42.28	80.27	5.12	2.33	1.80
Significance level	Ns	*	*	Ns	Ns	Ns	Ns

Ns: Not significant, *Significant at $p \leq .05$. Within each column, means with different letter(s) are significantly different according to LSD test at 0.05 level of probability.

4. Discussion

The results of the current study are in well agreement with those of Khan et al. (2007) who reported that K application significantly increased the grain yield of wheat crop (variety Naseer) in comparison with the control. The present research work is also in agreement with those of earlier works which indicated that K application resulted in significant increases in the grain yield of two wheat crop varieties over control (Tahir et al., 2008). The findings are also supported by Qiu et al. (2014) who indicated that the application of K significantly increased the grain yields of maize as compared with the control. The results are also maintained by previous researchers (Maurya et al., 2015) who reported that K application significantly affected the growth and yield of three different wheat varieties.

Similar results were recorded by Mohamed (2017) who reported that K application resulted in significant increases in wheat (cv. Seds 12) grain and straw yields compared with the control. The results also agree with Abd El-All et al. (2017) who indicated that biological, grain, and straw yields of two wheat varieties (Giza 168 and Sakha 93) were significantly increased with K application. However, an increasing trend for HI with increasing K rates was also reported. Similar results were reported by Jiang et al. (2018) who indicated that the K application incurred an increase in the yield of maize as compared with the control. The results are also in harmony with those obtained by Arif et al. (2019) who found that K addition enhanced TGW, grain, and biological yields of the wheat crop as compared to the control.

A previous study (Ali et al., 2019) also corroborated the obtained results which indicated that the grain yield, biological yield, TGW, and harvest index of the wheat crop were considerably affected by K fertilizer addition. The results of this work are also confirmed by Al-Taher and Al-Naser (2021) who found that K application significantly improved the average TGW, grain yield, biological yield, and harvest index of several wheat genotypes as compared with the control.

The results are also in agreement with Tesfaye et al. (2021) who reported that K fertilizer had a significant effect on wheat crop (variety Danda'a) growth, and yield. Hefny (2021) findings are also in line with the reported results which indicated that K application to the soil had a significant effect on yield and its components of four genotypes of durum wheat crop.

Similar results were also obtained by Godebo et al. (2021) who found that K application to soil induced a significant positive effect on the grain yield of wheat (variety Shomra) as compared with the control treatment. The results are also in agreement with Mazal et al. (2021) who mentioned that increasing the K application rate had a significant influence on the grain yield of wheat crop. The obtained results are also supported by Gu et al. (2021) who reported that foliar K application was very efficient in enhancing the yield and quality of two varieties of wheat crop.

The findings of this study agree with those of Dar et al., (2021) that showed the yield and seed quality of sunflower under arid and semi-arid regions were significantly improved by the K application. Sedri et al. (2022) also reported that the application of K in combination with N significantly increased the grain yield of wheat (Azar-2 variety) as compared with the control.

The results were also supported by the findings of Abro et al. (2022) who reported that K fertilizer application increased wheat crop growth and yield under environmental stress conditions. Earlier studies (Ulla et al., 2022) also maintained the existing study as they indicated that K application induced significant increases in the crop growth and dry matter production of the wheat crop compared with those recorded at the control treatment. Similar to the present results, Rawal et al. (2022) found that K application induced significant increases in wheat grain yield.

The low amounts of rainfall and its poor distribution in the second growing season at both sites may be the main probable reason responsible for the reduction in grain and biological yields, TGW, and height of the wheat crop of both varieties in comparison with those obtained in the first growing season. However, this negative impact of lower rainfall was more pronounced at the Mushagar site. The enhancement effect of K application on crop yield and growth attributes for both varieties and at both locations was very obvious. This could be attributed to the involvement of K in metabolic processes in plants which enhances its yield and quality (Cakmak, 2005; Arif et al., 2017; Tesfaye et al., 2021). Also, thanks to the key role of K in improving the plant's resistance to abiotic and biotic stresses (Qui et al., 2014; Dar et al., 2021).

5. Conclusion

Wheat crop showed a significant positive response towards the potassium soil application for both varieties and at both locations under rain-fed conditions in a semi-arid region. However, the magnitude of that response and the optimum rate of K depends on several factors, like variety and environmental conditions. The results indicated that the optimum K rate for Cham1 variety at the Mushaqar site was 40 kg K_2O/ha with a grain yield of 582 g/m^2 (8% higher than the control). Meanwhile, the optimum K rate for Um Qais variety at the Maru site was 40-60 kg K_2O/ha with a grain yield of 212-290 g/m^2 (14-25% higher than the control). Further studies on the optimum rate of K for other wheat crop varieties to improve their grain yields are highly recommended.

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Competing interests

The authors declare that they have no conflict of interest.

Author Contributions

Asad Alkhader selected the topic of the research work, analyzed data, and edited the manuscript. Amal Al-Khatib and Yahya Bani Khalaf reviewed the manuscript. Ali Mahasneh, Elaf Obeidat, Isra Salem, and Shehnaz Absharat conducted the field experiments. Awad Kaabneh and Ahmad Bataineh supervised the field works at the two sites. All authors approved the final version of the manuscript.

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