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Nutrient Content and Uptake of Wheat (*Triticum durum* L.) Fertilized with Potassium Sulfate under Semi-arid Conditions

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ABSTRACT

Background: Wheat productivity in semi-arid regions is relatively lower than the world's average due to environmental stress, largely drought and nutrient depletion. Potassium (K) enhances nutrient and water uptake, photoassimilate production and enzyme activation. The objective was to investigate the effect of different K application rates on nutrient content and uptake of wheat crop grown under rain-fed conditions. The impact of the K application on soil salinity was also examined.

Methods: Two local wheat (*Triticum durum* L.) varieties were investigated at two rain-fed sites. Five different rates of K were applied (0, 20, 40, 60 and 80 kg K_2O ha^{-1}).

Result: Potassium application rate at 40 to 60 kg K_2O ha^{-1} enhanced the nutrient uptake of the wheat crop; meanwhile, the soil salinity tended to increase.

Key words: Drought stress, Nutrient uptake, Photosynthesis, Potassium, Rain-fed, Wheat.

INTRODUCTION

Cereal crops are the main staple food worldwide, comprising over half of human calorie consumption. Wheat constitutes about 30% of cereal crops production and is the major food source for the ever-growing world population (Abd El-Mageed *et al*., 2023).

In Jordan, wheat is a major field crop mainly grown under rain-fed conditions. However, the country's wheat productivity of 2.39 t ha^{-1} (FAOSTAT, 2021) is relatively lower than the world's average (3.52 t ha^{-1}) (Godebo *et al*., 2021). Low rainfall, poor distribution, drought and unbalanced fertilization are the main limiting factors responsible for low cereal productivity (Laekemariam *et al*., 2018).

Nutrient content and uptake of crops are highly dependent on soil, crop types and genotypes, climatic factors, fertilizer forms and application rates (Oosterhuis *et al*., 2013; Luo *et al*., 2023; Kaur *et al*., 2024). Nutrient uptake is also strongly linked to rainfall amount and soil moisture content (Ragályi *et al*., 2023; Mazouz *et al*., 2024). Besides that, the nutritional status of crops is vital in their adaptation to environmental stress. In this context, K is leading in improving crop performance, photosynthetic efficiency, yield and quality under drought situations (Marschner, 2012; Sedri *et al*., 2022).

The current research is warranted as studies concerning vital issues linked to the best K nutrient management under rainfed conditions are inadequate in Jordan. Therefore, the effect of different application rates of soil-applied mineral K fertilizer on the wheat crop performance in terms of nutrient content and uptake of local wheat varieties in some rain-fed areas in Jordan was investigated. The effect on selected soil chemical properties was also studied.

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MATERIALS AND METHODS

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 of Jordan for two successive growing seasons (2019/2020 and 2020/2021). The stations were Mushaqar (796.3 m above sea level with a mean annual rainfall of 305 mm) and Maru (589 m above sea level with a long-term average rainfall of 400 mm). The soils at both locations were classified as vertisols (Alkhader *et al*., 2023).

Plant material

Two local wheat (*Triticum durum* L.) varieties, Cham 1 and Um Qais were tested at the Mushaqar and Maru sites, respectively. According to common cultural practices, the seeding rates were 120 and 130 kg ha^{-1}, respectively.

Cultural practices

The soil was cultivated and well-prepared at the two experimental sites. In the first season, sowing was carried out at the Maru and Mushaqar stations on the 3rd and 4th of

December 2019, respectively. Sowing in the second season was carried out on the 8th and 9th of December 2020, respectively. Diammonium phosphate (DAP) and urea were applied at 100 and 50 kg ha^{-1}, respectively. The total amount of DAP, half the quantity of urea and micronutrients in a chelating form at 10.0 kg ha^{-1} rate were broadcasted and incorporated into the soil as a basal dose. The second half of urea was added at the tillering stage. Potassium (as sulfate of potash, SOP (K_2SO_4) was applied to the soil at the time of sowing as per treatments. Plant harvesting was performed after complete plant maturity.

Treatments

Five levels of K: T_1 = 0 kg K_2O ha^{-1} (Control); T_2 = 20 kg K_2O ha^{-1}; T_3 = 40 kg K_2O ha^{-1}; T_4 = 60 kg K_2O ha^{-1} and T_5 = 80 kg K_2O ha^{-1}.

Experimental design and statistical analysis

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

Soil chemical and physical analysis

Before sowing, a composite surface soil sample (0-30 cm depth) was collected from the experimental site for physical and chemical analyses. Soil sampling was also made after plant harvesting, from three replicates. The samples were air-dried, crushed and passed through a 2 mm sieve for analysis. The following analyses were conducted: soil pH and salinity, as electrical conductivity (EC), (Bower and Wilcox, 1965), organic matter (Allison, 1965), calcium carbonate (Allison and Moodie, 1965), total N (Bremner, 1965), available P (Olsen and Dean, 1965), available K (Pratt, 1965), micronutrients (Chapman and Pratt, 1982) and soil texture (Day, 1965).

The soil of the Mushaqar Station was calcareous and clay in texture, exhibiting an alkaline reaction with an average pH of 7.7±0.1 and salinity of 0.891±0.182 dS m^{-1}. Meanwhile, the soil of the Maru Station was slightly calcareous and clay in texture, with an alkaline reaction, average pH and salinity of 7.7±0.1 and 0.651±0.066 dS m^{-1}, respectively.

Plant chemical analysis

Collected plant samples (grains and straws) were oven-dried (72°C to constant weight), ground and stored in clean dry plastic bags. Chemical analysis of representative samples for nutrients (N, P, K, Mg, Fe, Cu, Zn and Mn) from three replicates was also performed according to Chapman and Pratt (1982). Plant nutrient content was converted into nutrient uptake by multiplying with plant dry matter (Saudy *et al*., 2023).

RESULTS AND DISCUSSION

Effect of K on the nutrient content

Cham1 variety

The K application rate showed no significant effect on the nutrient content in wheat grain and straw of Cham1 variety at the Mushagar site in both seasons. The macronutrient (N, P, K and Mg) content in the wheat grain during the first season averaged at 1.51, 0.41, 0.51 and 0.221%, respectively for all the treaments. Meanwhile, the mean micronutrient (Cu, Fe, Mn and Zn) content in the grains was 6.07, 750.10, 65.32 and 35.39 mg kg^{-1}, respectively. On the other hand, the macronutrient content in the wheat straw averaged as 0.57, 0.043, 1.43 and 0.0231%, respectively. The mean of micronutrient content in the straw was 0.833, 757.20, 65.97 and 30.55 mg kg^{-1}, respectively in T_1 to T_5 treatments.

In the second season, the macronutrient content in the grains' macronutrient content averaged at 2.33, 0.33, 0.54 and 0.23%, respectively. Meanwhile, the mean of the grains' micronutrient content was 5.62, 146.00, 73.96 and 43.43 mg/kg, respectively. And, the straws' macronutrient content averaged at 1.00, 0.0627, 0.228 and 0.414%, respectively. Meanwhile, the mean of micronutrient content in straw was 0.430, 111.90, 40.45 and 2.91 mg/kg, respectively.

Um qais variety

K application rate, also, exhibited no significant effect on the plant grains' and straws' nutrient content of the Um Qais variety at the Maru site in both seasons. The average of grains' macronutrient (N, P, K and Mg) content in grain in the first season was 1.45, 0.58, 0.64 and 0.264%, respectively. Meanwhile, the grains' micronutrient (Cu, Fe, Mn and Zn) content averaged at 4.79, 240.55, 125.72 and 61.45 mg/kg, respectively. On the other hand, the average of macronutrient content was 0.54, 0.059, 0.785 and 0.310%, respectively, whereas the micronutrient content in straw averaged at 1.78, 124.48, 39.66 and 14.76 mg/kg, respectively.

Macronutrient content mean in grain, in the second season, was 1.91, 0.358, 0.456 and 0.206%, respectively. Meanwhile, the grains' micronutrient content average was 4.50, 173.65, 81.68 and 41.55 mg/kg, respectively. While, the straws' macronutrient content averaged at 1.959, 0.0203, 1.475 and 0.301%, respectively, the mean of micronutrient content in straw was 0.847, 431.50, 75.43 and 16.79 mg/kg, respectively.

Effect of K on nutrient uptake

Cham 1 variety

The macro and micro nutrient uptake in the wheat grains and straws, respectively of the Cham 1 variety at the Mushaqar site during the first season tended to increase as the K application rate increased (Table 1). However, K-treated plots showed significantly higher Mg uptake in the straw than the control.

On the other hand, during the second season, the K application rate has caused significant effects on the macro and micronutrient uptake in the grains (Table 2). The treatments, T_3, T_4 and T_5 presented significantly higher grain N, Cu and Mn uptake than the control. Meanwhile, T_4 and T_5 treatments showed significantly higher P and Zn uptake by grains than the control. However, there was an increasing trend in the grain uptake of K, Mg and Fe as the K application rate increased. The increments in the grain uptake of N, P, K and Mg in T_3 were at the rate of 49.26, 49.33, 45.23 and 40.52%, respectively relative to the control. Meanwhile, the respective increment in the uptake of micronutrients (Cu, Fe, Mn and Zn) in the grain in T_3 was in the tune of 51.47, 53.56, 51.13 and 48.87%, respectively relative to the control. The macro and micronutrient uptake in the wheat straws on the other side had shown an increasing trend with the K application rate (Table 2).

Um Qais variety

K application rate illustrated a significant effect on the uptake of K and Mg in the grains of the Um Qais variety during the first season with the highest values reported in T_5 with an increment of 42.0 and 38.7%, respectively, compared to the control (Table 3). However, an increasing trend in the grain uptake of N and P was seen as K rate increased. Similarly, K application rate significantly affected the grain uptake of micronutrients with the highest values reported in T_5. Increasing K rate has increased the N, P and K uptake in the wheat straw with the lowest and highest values in control (T_1) and T_5, respectively. However, K rate has a significant effect on the Mg uptake by straw with the highest value in T_5. K Potassium rate also has significantly affected the uptake of Cu, Fe and Mn by the straw, with the highest value in T_5. The Zn uptake by straw as well increased with the increasing K rate.

The macronutrient uptake by the grains of Um Qais variety displayed an increasing trend during the second season with the increase in the K application rate (Table 4). The Fe and Zn uptake in grain was found significantly higher in T_3, T_4 and T_5 than in the control. The uptake of Cu and Mn by the grains and all the macro and micronutrients by the straw increased as K application rate increased.

The noticeable response of the wheat nutrient uptake to K application could be attributed to the fact that the soils of the experimental sites were vertisols characterized by a high fixation capacity for K (Misskire *et al*., 2019). Hence, the indigenous K supply by such soils to support wheat crops might be insufficient. Irregular rainfall distribution might also contribute to instabilities in water and nutrient uptake (Gaj and Gorski, 2014).

Several researchers supported the above results (Dar *et al*., 2021; Bhattacharjee *et al*., 2022; Khatun *et al*., 2022; Lotfi *et al*., 2022; Ragályi *et al*., 2023; Nawaz *et al*., 2024) and mentioned that K fertilization could improve the wheat crop's nutrient uptake, yield, water use efficiency, chlorophyll content and photosynthetic rate. The increased nutrient uptake of the wheat crop could be attributed to the enhancement in the crop dry matter yield due to the external addition of K to the soil which can make K more readily

Table 1: Effect of different K levels on nutrient uptake by the grain and straw of the wheat crop (Cham 1 variety) under rain-fed conditions at Mushaqar Agricultural Station in the first season of 2019/2020.

Treatment	N	P	K	Mg	Cu	Fe	Mn	Zn
kg K_2O ha^{-1}	kg ha^{-1}				g ha^{-1}			
				Grain				
T1 = 0	81.04a	21.97a	27.65a	12.06b	32.47a	4077.8b	341.89b	185.57b
T2 = 20	82.96a	22.16a	27.85a	12.16b	33.73a	4151.9ab	376.40ab	196.97ab
T3 = 40	88.08a	23.34a	29.10a	12.36b	34.92a	4338.1ab	377.04ab	208.08ab
T4 = 60	88.75a	23.86a	29.63a	12.97b	35.94a	4363.2ab	381.00ab	208.8a
T5 = 80	90.47a	23.91a	29.99a	13.40a	35.97a	4445.6a	385.50a	209.48a
Mean	86.26	23.05	28.84	12.59	34.60	4275.3	372.36	201.80
$LSD_{0.05}$	20.23	5.02	3.24	1.00	4.21	357.5	41.99	26.18
Significance level	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
				Straw				
T1 = 0	45.77a	3.85a	122.76a	27.70b	7.23a	6469.0b	560.14b	263.86a
T2 = 20	52.90a	3.93a	129.89a	29.97ab	7.57a	6987.0ab	603.77ab	274.18a
T3 = 40	53.52a	4.03a	135.82a	30.96a	7.76a	7195.1a	627.98a	291.97a
T4 = 60	56.63a	4.05a	138.16a	32.29a	8.04a	7220.1a	629.91a	292.24a
T5 = 80	55.93a	4.10a	138.51a	32.41a	8.00a	7235.2a	630.49a	292.59a
Mean	52.95	3.99	133.03	30.67	7.72	7021.27	610.46	282.97
$LSD_{0.05}$	11.96	0.84	18.39	3.18	1.34	673.46	77.15	57.97
Significance level	Ns	Ns	Ns	*	Ns	Ns	Ns	Ns

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

Table 2: Effect of different K levels on nutrient uptake by the grain and straw of the wheat crop (Cham 1 variety) under rain-fed conditions at Mushaqar Agricultural Station in the second season of 2020/2021.

Treatment	N	P	K	Mg	Cu	Fe	Mn	Zn
kg K_2O ha^{-1}	kg ha^{-1}					g ha^{-1}		
				Grain				
T1 = 0	1.823c	0.24c	0.44b	0.20b	0.44b	11.52b	5.69c	3.45c
T2 = 20	2.94bc	0.43bc	0.70ab	0.33ab	0.700ab	18.25ab	8.45bc	4.98bc
T3 = 40	3.59ab	0.48abc	0.79ab	0.340ab	0.90a	24.80a	11.64ab	6.74abc
T4 = 60	4.28ab	0.61ab	1.00a	0.400ab	1.05a	25.72a	14.30ab	8.33ab
T5 = 80	4.73a	0.71a	1.07a	0.44a	1.10a	29.10a	15.00a	8.81a
Mean	3.47	0.49	0.800	0.34	0.84	21.88	11.02	6.46
$LSD_{0.05}$	1.73	0.24	0.47	0.21	0.45	13.12	5.94	3.82
Significance level	*	*	Ns	Ns	*	Ns	*	*
				Straw				
T1 = 0	29.99a	1.80a	6.68a	12.73a	1.31a	316.34b	118.53a	8.30a
T2 = 20	29.68a	1.91a	7.10a	12.18a	1.30a	328.25ab	127.29a	8.82a
T3 = 40	29.60a	1.87a	7.01a	12.43a	1.34a	339.32ab	119.73a	9.10a
T4 = 60	31.37a	2.00a	7.10a	13.17a	1.33a	364.86ab	128.12a	9.08a
T5 = 80	32.46a	2.01a	6.97a	12.97a	1.30a	366.95a	126.98a	9.24a
Mean	30.62	1.92	6.97	12.69	1.32	343.14	124.13	8.91
$LSD_{0.05}$	3.48	0.32	0.96	3.72	0.26	49.71	27.35	1.41
Significance level	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Ns: Not significant, *: Significant at p≤0.05. Within each column, means with a different letter(s) are significantly different according to the LSD test at 0.05 probability level.

Table 3: Effect of different K levels on the nutrient uptake by the grain and straw of the wheat crop (Um Qais variety) under rain-fed conditions at Maru Agricultural Station in the first season of 2019/2020.

Treatment	N	P	K	Mg	Cu	Fe	Mn	Zn
kg K_2O ha^{-1}	kg ha^{-1}					g ha^{-1}		
				Grain				
T1 = 0	33.88b	13.61b	14.92c	6.04b	11.063b	560.48c	291.94c	141.71c
T2 = 20	39.45ab	15.92ab	17.46bc	7.31ab	13.13ab	653.46bc	341.45bc	166.41bc
T3 = 40	39.92ab	15.98ab	17.58bc	7.20ab	13.37ab	662.48bc	344.38b	167.91b
T4 = 60	41.72ab	16.48ab	17.97b	7.77a	13.74a	693.61ab	363.73ab	178.99ab
T5 = 80	47.45a	18.53a	21.19a	8.38a	15.52a	791.99a	413.71a	203.32a
Mean	40.48	16.11	17.82	7.34	13.36	672.41	351.04	171.67
LSD0.05	8.44	3.20	2.71	1.41	2.49	111.10	50.51	25.51
Significance level	Ns	Ns	**	*	*	*	**	**
				Straw				
T1 = 0	31.44b	3.33b	45.60b	17.44b	10.25b	717.42b	229.13b	84.90b
T2 = 20	31.90b	3.44b	46.13b	17.52b	10.35b	719.63b	230.00b	84.66b
T3 = 40	34.02ab	3.62ab	48.82ab	18.99b	11.28b	788.35b	252.11b	95.03ab
T4 = 60	34.85ab	3.82ab	51.73ab	19.52ab	11.69ab	814.77ab	257.99ab	95.66ab
T5 = 80	40.93a	4.62a	60.08a	23.30a	13.52a	956.75a	301.64a	113.87a
Mean	34.630	3.77	50.47	19.35	11.42	799.39	254.17	94.82
LSD0.05	8.67	1.01	12.20	4.01	2.15	158.74	48.29	25.15
Significance level	Ns	Ns	Ns	*	*	*	*	Ns

Ns: Not significant, * and **: Significant at p≤0.05 and p≤0.01, respectively. Within each column, means with a different letter(s) are significantly different according to the LSD test at 0.05 probability level.

available (Jat *et al*., 2014). Similar results were reported by Dakshina *et al*. (2015) in rice.

The present findings are linked to the investigated wheat crop varieties grown under the prevailing environ-mental conditions. And, adopting cultural practices different from the present study might produce different results.

Effect of K application on soil chemical properties

Mushagar site

The K application rate showed no significant effect on the studied soil chemical properties at the Mushaqar site in the first season. However, soil salinity increased as K application rate increased, from 0.442 dS m^{-1} in T_1 (control) to 0.5132 dS m^{-1} in T_4 (+16%). The average values of the soil pH, EC and organic matter for all treatments were 7.68, 0.472 dS m^{-1} and 0.229%, respectively. The mean values of soil nutrients *viz*., N, P, K, Fe, Mn, Zn and Cu were noted as 0.075%, 17.24 mg kg^{-1}, 506.10 mg kg^{-1}, 0.756 mg kg^{-1}, 7.88 mg kg^{-1}, 0.61 mg kg^{-1} and 1.33 mg kg^{-1}, respectively.

On the other hand, K application rate significantly affected soil salinity in the second season. The increments in soil salinity in T_3 (0.468 dS m^{-1}), T_4 (0.421 dS m^{-1}) and T_5 (0.555 dS m^{-1}) treatments were 40, 33 and 49%, respectively, compared to the control (0.281 dS m^{-1}). The soil pH, EC and organic matter content averaged as 8.14, 0.408 dS m^{-1} and 0.94%, respectively, whereas the average of soil nutrients (N, P, K, Fe, Mn, Zn and Cu) was 0.066%, 8.12, 521.7, 0.877, 3.71, 0.531 and 1.132 mg/kg, respectively.

Maru site

No significant effect of for the K application was noticed on the soil chemical properties at the Maru site in both seasons. However, soil salinity increased with increasing K rates in the first season, where it increased from 0.297 dS m^{-1} in T_1 to 0.380 dS m^{-1} in T_4 (+28%). The mean of soil pH, EC and organic matter average values for all treatments were was 8.12, 0.347 dS/m and 1.30%, respectively. Meanwhile, the soil nutrients (N, P, K, Fe, Mn, Zn and Cu) averaged at 0.130%, 20.16 mg/kg, 334.40 mg/kg, 0.743 mg/kg, 5.23 mg/kg, 1.14 mg/kg and 3.27 mg/kg, respectively.

Similarly, during the second season, soil salinity also showed an increasing tendency as K application rate increased from 0.325 dS/m^{-1} at T_1 to 0.453 dS/m^{-1} at T_5 (+39%). The average of soil pH, EC and organic matter content averages was 8.10, 0.395 dS/m^{-1} and 1.72%, respectively. Meanwhile, the soil nutrients (N, P, K, Fe, Mn, Zn and Cu) averaged at 0.108%, 14.68 mg/kg, 355.84 mg/kg, 1.78 mg/kg, 0.702 mg/kg, 2.13 mg/kg and 1.48 mg/kg, respectively.

The shortage in seasonal rainfall during the second growing season might be responsible for the insufficient leaching of soluble salts that usually accompany the application of chemical fertilizers. This could eventually increase the salinity of the soil. However, the possible reason for the non-significant effect of the chemical fertilizers on soil pH could be attributed to the high buffering capacity of the

Table 4: Effect of different K levels on nutrient uptake by the grain and straw of the wheat crop (Um Qais variety) under rain-fed conditions at Maru Agricultural Station in the first season of 2020/2021.

Treatment	N	P	K	Mg	Cu	Fe	Mn	Zn
kg K_2O ha^{-1}	kg ha^{-1}					g ha^{-1}		
				Grain				
T1 = 0	35.16b	6.83a	7.82b	3.80b	7.88 b	315.06b	147.45b	65.90c
T2 = 20	37.45b	7.14a	8.84ab	4.05ab	8.86ab	314.14b	157.83ab	74.29bc
T3 = 40	39.45ab	6.97a	10.83a	4.36ab	10.29a	377.03ab	190.10ab	95.08ab
T4 = 60	41.85ab	8.21a	10.52a	4.65ab	9.54 ab	398.67a	192.43a	103.93a
T5 = 80	49.15a	8.66a	10.61a	5.10a	11.03a	441.10 a	181.29ab	103.97a
Mean	40.61	7.56	9.72	4.39	9.52	369.20	173.82	88.63
$LSD_{0.05}$	10.42	1.89	2.52	1.06	2.29	82.82	43.13	24.46
Significance level	Ns	Ns	Ns	Ns	Ns	*	Ns	*
				Straw				
T1 = 0	85.97a	0.91a	67.48a	13.34a	4.26a	1838.3a	343.08a	75.13a
T2 = 20	93.91a	0.91a	66.70a	13.87a	3.89a	2062.5a	350.91a	76.21a
T3 = 40	87.11a	0.89a	65.97a	13.75a	3.27a	1944.5a	335.93a	69.08a
T4 = 60	96.54a	1.09a	74.58a	14.43a	3.96a	2122.7a	378.28a	92.62a
T5 = 80	102.54a	0.99a	76.29a	16.13a	4.68a	2187.7a	379.80a	85.22a
Mean	93.21	0.96	70.20	14.30	4.01	2031.1	357.60	79.65
$LSD_{0.05}$	19.23	0.36	25.45	2.90	1.74	469.1	92.18	44.39
Significance level	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Ns: Not significant, *: Significant at p≤0.05. Within each column, means with a different letter(s) are significantly different according to the LSD test at 0.05 probability level.

calcareous soil (Alkhader and Abu Rayyan, 2015). The above results were in conformity with those of Amsalu and Beyene (2020) and (Govada *et al*., 2024) who reported that chemical fertilizers had increased soil EC but had no significant effect on soil pH. However, the nonsignificant variations in the soil's available nutrients after harvest may be attributed to the balance between the addition of nutrients through fertilization and the withdrawal of nutrients by the crop. The results follow the findings of Sharma and Jain (2014).

CONCLUSION

The results revealed that K application rate positively affected the nutrient uptake in wheat and increased soil salinity. K application rate at 40 to 60 kg K_2O ha^{-1} (as SOP) can be recommended at both Mushaqar and Maru sites. Judicious nutrient management, particularly K, should be practiced in semi-arid regions to help improve the nutrient uptake for higher grain yield and quality in wheat. Further research is highly recommended to investigate the other wheat varieties' response to K application under similar environmental conditions.

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Conflict of interest

The author declares that there are no conflicts of interest regarding the publication of this article.

REFERENCES

Abd El Mageed, T.A., Semida, W.M., Abdou, N.M. and Abd El Mageed, S.A. (2023). Coupling effects of potassium fertilization rate and application time on growth and grain yield of wheat (*Triticum aestivum* L.) plants grown under Cd contaminated saline soil. *Journal of Soil Science and Plant Nutrition*. **23(1):** 1070-1084. doi.org/10.1007/s42729-022-01104-3.

Alkhader, A.M.F. and Abu Rayyan, A.M. (2015). The impact of phosphorus fertilizers on nutrients content and uptake in lettuce (*Lactuca sativa* L.) and on selected chemical properties of a calcareous soil. *Jordan Journal of Agricultural Sciences*. **11(4):** 1021-1035.

AlKhader, A.M.F., Al-Khatib, A., Kaabneh, A., Mahasneh, A., Obeidat, E., Bani Khalaf, Y., Bataineh, A., Salem, I. and Absharat, S. (2023). Response of wheat crop to potassium fertilization under rain-fed conditions in semi-arid regions. *Sustainable Agriculture Research*. **12(1):** 51-60. doi: 10.5539/sar.v12n1p51.

Allison, L.E. (1965). Organic carbon. In: Methods of Soil Analysis. Part 2.Chemical and Microbiological Properties, Agronomy 9. [Black, C. (Eds).]. *American Society of Agronomy, Madison, Wisconsin*. pp. 1376-1378.

Allison, L.E. and Moodie, C.D. (1965). Carbonates. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, Agronomy 9. (Black, C. Eds.). American Society of Agronomy, Madison, Wisconsin. doi.org/10.2134/agronmonogr9.2.c40. pp.1379-1396.

Amsalu, S. and Beyene, S. (2020). Effects of lime and phosphorous application on chemical properties of soil, dry matter yield and phosphorus concentration of barley (*Hordeum vulgare*) grown on Nitosols of Emdibir, Southern Ethiopia. *Journal of Soil Science and Environmental Management*. **11(4):** 131-141. doi.org/10.5897/JSSEM2020.0837.

Bhattacharjee, S., Bhale, V.M., Kumar, P. and Kumar R. (2022). Effect of potassium and zinc nutrition on growth and yield of short duration maize (*Zea mays* L.) under dryland *Vertisols*. *Indian Journal of Agricultural Research*. **56(1):** 22-27. doi: 10.18805/IJARe.A-5892.

Bower, C.A. and Wilcox, L.V. (1965). Soluble salts. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, Agronomy 9. (Black, C. Eds.). American Society of Agronomy, Madison, Wisconsin. pp. 933-951.

Bremner, I.M. (1965). Total Nitrogen. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, Agronomy 9. (Black, C. Eds.). *American Society of Agronomy, Madison, Wisconsin*. https://doi.org/10.2134/agronmonogr9.2.c32. pp.1149-1178.

Chapman, H.D. and Pratt, P.F. (1982). Methods of Analysis for Soils, Plants and Waters. Second Edition. Oakland, CA: Agriculture Division, California University.

Dakshina Murthy, K.M., Upendra Rao, A., Vijay, D. and Sridhar, T.V. (2015). Effect of levels of nitrogen, phosphorus and potassium on performance of rice. *Indian Journal of Agricultural Research*. **49(1):** 83-87. doi: 10.5958/0976-058X.2015.00012.8.

Dar, J.S., Cheema, M.A., Rehmani, M.I.A., Khuhro, S., Rajput, S., Hessini, K. (2021). Potassium fertilization improves growth, yield and seed quality of sunflower under drought stress at different growth stages. *PLOSONE*. 16(9). https://doi.org/10.1371/journal.pone.0256075.

Day, T.R. (1965). Particle Size Analysis. In: Methods of Soil Analysis. Part 2.Chemical and Microbiological Properties, Agronomy 9. (Black, C. Eds.). American Society of Agronomy, Madison, Wisconsin. pp.562-566.

FAOSTAT. (2021). FAO DATA-06-19-2021. Retrieved from. http://www.fao.org/faostat/en/#data/QC.

Gaj, R. and Gorski, D. (2014). Effects of different phosphorus and potassium fertilization on contents and uptake of macro-nutrients (N, P, K, Ca, Mg) in winter wheat I Contents of macronutrients. J*ournal of Central European Agriculture*. **15(4):** 169-187. doi: 10.5513/JCEA01/15.4.1526.

Godebo, T., Laekemariam, F. and Loha, G. (2021). Nutrient uptake, use efficiency and productivity of bread wheat (*Triticum aestivum* L.) as affected by nitrogen and potassium fertilizer in Keddida Gamela Woreda, Southern Ethiopia. *Environmental System Research.* **10:** 12. https://doi.org/10.1186/s40068-020-00210-4.

Govada, D.S., Mrudhula, K.A., Sunil, K, Ramesh, G., Kishore, B.G. and Siddartha, N.B. (2024). Evaluation of saline water effects on use efficiency and soil nutrient availability of maize (*Zea mays* L.) under drip fertigation. *Plant Science Today*. **11(2):** 486-495. https:/doi.org/10.14719/pst.2871.

Jat, G., Majumdar, S.P., Jat, N.K. and Mazumdar, S.P. (2014). Effect of potassium and zinc fertilizer on crop yield, nutrient uptake and distribution of potassium and zinc fractions in Typic Ustipsamment. *Indian Journal of Agricultural Sciences*. **84(7):** 832-838, July 2014/Article https://doi.org/10.56093/ijas.v84i7.41994.

Kaur, G., Singh, I., Behl, R.K. and Dhankar, A. (2024). Effect of different integrated nutrient management approaches on growth, yield attributes and yield of wheat (*Triticum aestivum* L.) crop: A review. *Asian Journal of Soil Science and Plant Nutrition.* **10(1):** 457-468. doi: 10.9734/AJSSPN/2024/v10i1252.

Khatun, S., Zaman, F., Hossain, M.M., Sarker, M.J. and Hasan, A.K. (2022). Split application of varying potassium (K) rates influence wheat yield and K use efficiency. *Fundamental and Applied Agriculture.* **7(3):** 168-178. doi: 10.5455/faa.107436.

Laekemariam, F., Kibret, K. and Shiferaw, H. (2018). Potassium (K)-to-magnesium (Mg) ratio, its spatial variability and implications to potential Mg-induced K deficiency in Nitisols of Southern Ethiopia. *Agriculture and Food Security*. 7(13). https://doi.org/10.1186/s40066-018-0165-5.

Lotfi, R., Abbasi, A., Kalaji, H.M., Eskandari, I., Sedghieh, V., Khorsandi, H., Sadeghian, N., Yadav, S. and Rastogi, A. (2022). The role of potassium on drought resistance of winter wheat cultivars under cold dryland conditions: Probed by chlorophyll a fluorescence. *Plant Physiology and Biochemistry*. **182:** 45-54. https://doi.org/10.1016/j.plaphy.2022.04.010.

Luo, L., Zhang, X., Zhang, M., Wei, P., Chai, R., Wang, Y., Zhang, C. and Siddique, K.H.M. (2023). Improving wheat yield and phosphorus use efficiency through the optimization of phosphorus fertilizer types based on soil P pool characteristics in calcareous and non-calcareous soil. *Agronomy*. **13:** 928. https://doi.org/10.3390/agronomy13030928.

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants. Third Edition. Academic Press. pp. 649.

Mazouz, L., Boussaa, A. and Kentour, A. (2024). The effect of phosphorous utilization efficiency on durum wheat cultivars under semi-arid environmental conditions. African *Journal of Food, Agriculture, Nutrition and Development*. **24(2):** 25603-25627. https://doi.org/10.18697/ajfand.127.23185.

Misskire, Y., Mamo, T., Taddesse, Abi M. and Uri, Y. (2019). The effect of potassium on yield, nutrient uptake and efficiency of teff (*Eragrostis tef* Zucc. Trotter) on vertisols of northwestern Ethiopian highlands. *Journal of Plant Nutrition*. **42(4):** 307-322. doi: 10.1080/01904167.2018.1554681.

Nawaz, A., Bashir, M.A., Ahmed, W., Ahmad, I., Rehim, A., Ikram, R.M., Shah, S.S.H., Khurshid, M.Y., Rusan, M.J., Lubani, R., Saleem, S., Haq, T.U. and Ali, M.A. (2024). Potassium and zinc improves physiological performance, nutrient use efficiency and productivity of wheat. *Front. Plant Sci*. **15:** 1363248. doi: 10.3389/fpls.2024.1363248.

Olsen, S.R. and Dean, L.A. (1965). Phosphorus. In: Methods of Soil Analysis. Part 2.Chemical and Microbiological Properties, Agronomy 9. (Black, C. Eds.). American Society of Agronomy, Madison, Wisconsin. pp.1035-1048.

Oosterhuis, D.M., Loka, D.A. and Raper, T.B. (2013). Potassium and stress allev*i*ation: Physiological functions and management of cotton. *Journal of Plant Nutrition and Soil Science*. **176(3):** 331-343. https://doi.org/10.1002/jpln.201200414.

Pratt, P.F. (1965). Potassium. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, Agronomy 9. (Black, C. Eds.). *American Society of Agronomy, Madison, Wisconsin*. https://doi.org/10.2134/agronmonogr9.2.c20.1022-1030.

Ragályi, P., Szabó, A., Rékási, M., Csathó, P. and Csontos, P. (2023). Effect of different macronutrient supply levels on the drought tolerance of rainfed grass based on biomass production, water use efficiency and macroelement content. *Horticulturae.* **9:** 1337. https://doi.org/10.3390/ horticulturae 9121337.

SAS Institute Inc. 2002. SAS. Cary, North Carolina, USA.

Saudy, H.S., Salem, E.M.M. and Abd El-Momen, W.R. (2023). Effect of potassium silicate and irrigation on grain nutrient uptake and water use efficiency of wheat under calcareous soils. *Gesunde Pflanzen*. **75:** 647-654. https://doi.org/10.1007/s10343-022-00729-9.

Sedri, M.H., Roohi, E., Niazian, M. and Niedbała, G. (2022). Interactive effects of nitrogen and potassium fertilizers on quantitative-qualitative traits and drought tolerance indices of rainfed wheat variety. *Agronomy.* **12(3):** 1-17. https://doi.org/10.3390/agronomy12010030.

Sharma, S.K. and Jain, N.K. (2014). Change is soil fertility as influenced by varying levels of fertilization to *Kharif* crops and different wheat based cropping systems in southern Rajasthan, India. *Indian Journal of Agricultural Research*. **48(5):** 352-359. doi: 10.5958/0976-058X.2014.01314.6.