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Evaluation of the Efficiency of Foliar Potassium Applications as Drought Mitigation

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A FIELD experiment was performed to investigate the mitigation effects of foliar K on wheat under drought stress. Foliar potassium treatments, either in terms of sources and concentrations, relatively increased wheat water use by about 111 and 117 and 114 % for the foliar application of K_2O-K_2SO_4 and 120, 120 and 117% for the foliar application of K_2O-K_2SiO_3 at concentration treatments of 0.5, 1.0, and 2% respectively relative to control treatment (0.0 K_2O) = 100. The positive mitigation effects of K on wheat water use were more pronounced for using K_2SiO_3 than K_2SO_4 respectively. The foliar application of potassium either in the forms of K_2SO_4 or K_2SiO_3 at the different tested concentrations increased the grain production per unit of water use. Where water use efficiency reached about 2.23, 2.34 and 2.27 kg/m^3 for K_2SO_4 and 2.41, 2.39 and 2.33 kg/m^3 for K_2SiO_3 at concentrations of 0.5, 1 and 2% K_2O respectively compared to 1.99 kg/m^3 for the control treatment. It could be concluded that the foliar K application may act positively act to mitigate drought stress particularly when applied at the beginning of the emergence, tillering and flowering stages of wheat.

Keywords: wheat, drought stress, K-mitigation, water use efficiency, foliar spray of potassium.

1. Introduction

Increases in drought with global climate change will decrease plant growth, thereby decreasing food production in both natural ecosystems and agricultural systems. As plants are the main source of food for most humans, increases in drought will increase human hunger, and this will be exacerbated by population growth (Bista et al. 2018). Water shortages are a universal issue that poses a serious threat for crop production (Waraich et al. 2020; El-Nady and Shalaby 2014). Drought stress is a principle environmental factor limiting growth and yield of crops (Sangakkara et al. 2001). Drought stress inhibits the photosynthesis and radiation use efficiency of plants, because of reduced synthesis and the presence of photosynthetic pigments (Siddique et al. 2016). Wheat (*Triticum aestivum* L.) is one of the most important cereals crops for food for more than 3rd population of the worlds. Drought and water deficit are important abiotic stresses affecting wheat production worldwide. About 45 million hectares of wheat production area is suffered from periodic drought-stress (Byerlee and Moya, 1993).

Potassium silicates have a central role in the tolerance of some environmental stresses such as drought, heat and salt stress (El-Tayeb, 2005). Both of K and Si participating in the regulation of stomatal closure, transpiration and drought stress tolerance (Shakirova et al. 2003). Potassium being the most mobile plant nutrient it performs function in osmotic regulation (Beg and Sohrab, 2012) and promote drought tolerance by maintaining water balance (Cakmak, 2005). Plant cells can mitigate the unfavorable effects of drought stress by lowering the depletion of cellular water and regaining cellular turgor, (Zhang et al. 2009a, b). The foliar sprays of potassium significantly improved the morphological and biochemical characteristics of wheat particularly when grown in the presence of drought stress condition (Kunrath et al. 2018). Srivastava et al. (2019) confirmed that the foliar application of potassium is a highly mitigate the drought stress effects on wheat to enhance the crop yield. The harmful impacts of drought stress on the growth of wheat are minimized through the foliar spray of potassium (El-Ashry et al. 2005). Application of potassium improved the ability of plant to tolerate osmotic stress, including drought by minimizing its negative

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effects on plant and enhancing the uptake and translocation of water to make a balance (Adhikari et al. 2019). Sulfur (S) plays a vital role in mitigating stress due to abiotic factors within a crop. The increasing demand for SO_4 during adaptation to moisture stress is evident that it plays a vital role in strengthening the defense system (Usmani et al. 2020). A specific type of signal is produced due to interaction with abscisic acids with the SO_4 that triggers stomatal closure under water shortage conditions (Batista et al. 2020). The metabolism of S can form the various defensive compounds (phytochelatins, methionine, glutathione and cysteine) that enhance the plant's strength to resist abiotic stress (Honsel et al., 2012; Maamoun 2014). Silicon (Si) is a valuable nutrient that provides excellent benefits at various growth stages, mainly when there is less moisture (Kovács et al., 2022). Exogenously applied Si diminished the adverse effect of water stress in various crops, including monocots (wheat, sorghum). The Si is accumulated below the cuticle layer of aerial parts of plants and minimizes transpiration by closing stomata (Thorne et al., 2020). The main purposes of this work were to investigate the mitigation of drought stress in winter wheat crop by foliar application of potassium accompanied with sulfate or silicate as co-ions.

3 Materials and Methods

2.1 Field experiment

A field experiment was conducted to evaluate the mitigation effect of the foliar spray of two different potassium sources on winter wheat (*Triticum aestivum*) grown under water stress conditions. This experiment was performed in 210 m^2 of flooded irrigated area during winter 2021. This experiment was performed in a complete randomized block design to study the effect of potassium foliar treatment with three replications. The field experiment was conducted to evaluate the possibility of using foliar potassium application for mitigation the negative impact of drought stress on wheat plants such as that grown at the edges of the field. This experiment was carried out during winter 2021-2022 in Al-Munira village, Al-Qanater Al-Khyreya, Qalyubia Governorate (30°14'54.4"N 31°07"12.5"E), 31 Km North-West far from Agriculture Faculty, Ain Shams University. The tested winter wheat seeds (Masr 1 CV) were taken from the Agricultural Research Center, Giza, Egypt. Seeds of wheat had 12 hours pre-soaking in tap water before sowing. After seed germination, irrigation was carried out up to 100% total available soil water. At four leaves stage of the seedlings, extra plants were thinned then water stress treatments were started.

This field experiment included three irrigation treatments: which are 80, 60 and 40% of the readily available water (RAW) for the wheat crop based on gravimetric tracking of the change in soil moisture content. The experimental area was divided into three equal plots, one for each irrigation treatment. Representative soil samples were collected weekly from each plot to determine soil moisture content as a base for determining the time and amount of irrigation that should be added to each irrigation treatment. In this experiment seven irrigations were recorded during the growth season. The readily available water (RAW) in the plant root zone of winter wheat was calculated using the following equations described by Allen **(1998)**:

$$RAW = p \times TAW$$

$$TAW = 1000\ (\theta FC - \theta PWP) \times R_d$$

Where: RAW is the readily available water in the plant root zone in mm, TAW is the total available soil water in the root zone in mm, p is the average fraction of TAW that can be depleted from the root zone before moisture stress, θFC is the water content at field capacity in m^3/m^3, θPWP is the water content at permanent wilting point in m^3/m^3, and Rd is the rooting depth in cm, the effective R_d of winter wheat in the studied soils. The average allowable water depletion (p) was taken as 0.5 for winter wheat (FAO, 2012). The values of θFC and θPWP are shown in **Table 1**. This field experiment included potassium foliar fertilization treatments that involved two sources: potassium sulfate (K_2SO_4) and potassium silicate (K_2SiO_3), each in four concentrations of 0, 0.5, 1, and 2% K_2O. The different concentrations of potassium sources were sprayed in three consecutive applications during the growing season, at the beginning of the emergence stage, tillering stage and flowering stage or at the plant age of 21, 42 and 63 days from sowing respectively.

2.2 Preparation of the foliar treatments

Potassium foliar spray stock solution of 5 % K_2O was prepared to use as drought stress mitigators by dissolving 500 ml of liquid potassium silicate 10% K_2O or 100 g of potassium sulfate 50% K_2O in 1 liter measuring flask of distilled water. The final potassium foliar spray of 0.5, 1.0 and 2.0% K_2O were prepared by dissolving 50, 100 and 200 ml/L respectively. Potassium sulfate "Ever Sol-SOP 0/0/50" (50% K_2O and 18% S) was imported from Finland by Evergrow Company (www.evergrowfert.com). Liquid Potassium silicate (10% K_2O w/v, 25% SiO_2 w/v), produced by El-Nasr for Intermediate Chemicals Company, Egypt.

2.3 Field data

Wheat plants in field experiment were fertilized using fertilization program as recommended by Ibrahim (2013). Similar rates of potassium were added to plants in all treatments. At four leaf stage of the seedlings, extra plants were thinned. At the end of the field experiments or after 148 days from sowing, wheat plants were harvested. The spikes were collected and threshed manually. The weight of wheat grain yield was estimated for each treatment. The total amount of wheat water use during the growing season for the different irrigation and potassium foliar fertilization treatments were recorded.

2.4 Soil, plant and water analyses:

Representative soil and water samples were taken before cultivation at 0-30 cm depth for some physical and chemical analyses (**Table 1**a **and 1**b). soil physical characteristics (i.e., SP, FC and PWP, $CaCO_3$, Real particle density (P_d), bulk density (B_d) and soil texture were determined using the methods described by Jacob et al. (2002). Soil organic matter (OM) was determined based on the Walkley-Black chromic acid wet oxidation method as described by McLeod, S (1973). Electrical conductivity ($EC_{1:5}$) was determined in 1:5 soil: water extract using an EC meter (Model YSI 32). In the 1:5 soil:water extract, water soluble Ca, Mg, K, Na, Cl, HCO_3 and CO_3 were determined using the standard methods of chemical analysis as described by Jackson (1973). Wheat shoots were collected at the harvest and prepared for chemical analyses to determine N, P, and K contents using the methods described by Jackson (1973).

2.5 Statistical Analyses

Analysis of variance (ANOVA) for the data was performed using SAS, V.9. (SAS (1976). Mean separation was performed only when the F-test indicated significant differences among the treatments, (at P≤ 0.05) according to Duncan's multiple range test.

3. RESULTS AND DISCUSSIONS

3.1. Specifications of the experimental site

Data in **Tables 1**a **and 1**b show some physical and chemical properties of the soil of the experimental area. The values of saturation percentage (SP), field capacity (FC), permanent wilting point (PWP), real particle density (R_d) and bulk density (B_d) were about 53.7, 36.5, 20.9%, 2.43 and 1.25 g/cm^3 (**Table 1**a). In addition, the soil texture was clay in the experimental area.

Table 1a. Some physical and chemical properties of soil in the experimental area.

Some soil physical properties of the experimental area										
SP	FC	PWP	TAW	Pd	Bd	$CaCO_3$	Sand	Silt	Clay	Soil texture
%				g/cm^3		%				
53.7	36.5	20.9	15.6	2.43	1.25	1.85	17.1	35.4	47.5	Clay

Some soil chemical properties of the experimental area											
OM %	$pH_{1:2.5}$	$EC_{1:5}$ dS/m	Salinity ppm	Ca^{++}	Mg^{++}	K^+	Na^+	HCO_3^-	$CO_3^=$	Cl^-	$SO_4^=$
					meq/l in 1:5 soil:water extracts						
0.24	8.1	0.48	0.29	1.63	0.31	0.10	0.14	1.31	0.10	0.48	0.29

Table 1b. Some chemical properties of irrigation water in the experimental area.

pH	EC dS/m	Salinity, ppm	Ca^{++}	Mg^{++}	K^+	Na^+	HCO_3^-	$CO_3^=$	Cl^-	$SO_4^=$
			meq/l							
7.40	1.10	704	2.20	1.65	0.10	7.15	1.10	ND*	8.70	1.30

* ND: Not detected

No adverse effects may expect on wheat plant grown under the obtained values of all the physical and chemical properties shown in **Table 1**a. Electrical conductivity (EC) of irrigation water as shown in **Table 1**b is suitable for wheat as mentioned by Steduto et al. (2012). Data in **Table 2** show the monthly average of some meteorological data for Qalyubia governorate during the period of the experiment. However, it could be observed that the recorded weather parameters were appropriate for wheat growth during the winter season.

3.2. Effects of foliar potassium applications on some growth parameters of wheat.

Data in **Table 3** and **Fig. 1** show the effects of potassium as drought mitigation on some growth parameters of wheat crop grown under different rates of irrigation water stressed to 40% of readily available water (RAW). Results indicated that the application of different potassium sources or concentrations had no significant effects on wheat shoot length and shoot water content under the different irrigation water treatments, (80, 60 and 40 %RAW). A slight increase in shoot dry weight as affected by increasing soil moisture stress from 80% to 40 %RAW either under the foliar application of both K_2SO_4 and K_2SiO_3. This result is in agreement with that observed by Hussain et al. (2016) who mentioned that the plant height reduced due to the lack of water in the protoplasm, reduced relative turgidity and reduced division and elongation of cell. No significant difference was observed in wheat shoot dry weight as response to drought or foliar potassium treatments.

Table 2. Monthly average of some meteorological data for Qalyubia governorate during 2021-2022, 11-12-2021 – 22-5-2022 (148 days for the field experiment).

Month	Time date	T_{mean}	T_{min}	T_{max}	RH_{mean}	RH_{min}	RH_{max}	U_{mean}	U_d	Un	N	N	Rs
			C°			%			Km/h		hrs/d		MJ/m²
Dec 2021	11-20	16.2	19.2	13.0	61.8	79.4	44.7	10.2	24.5	1.45	10.3	6.35	11.1
	21-31	14.6	18.3	11.1	63.5	84.3	44.0	7.23	19.8	1.20	10.3	7.18	11.9
Jan 2022	1-10	15.0	18.7	11.0	66.8	85.3	45.7	18.1	32.4	5.80	10.7	6.26	11.7
	11-20	13.5	16.6	10.8	49.3	67.4	35.5	16.0	28.5	3.82	10.7	7.98	13.4
	21-31	12.0	15.4	8.82	55.1	71.8	38.7	11.8	22.6	1.40	10.7	8.82	14.2
Feb 2022	1-10	14.9	18.7	10.9	52.4	73.2	35.2	16.2	29.5	4.20	10.7	6.84	14.8
	11-20	14.2	18.3	9.80	67.6	89.3	45.2	12.2	25.9	1.8	10.7	8.57	16.9
	21-28	16.6	20.8	12.5	54.2	74.1	32.4	15.9	27.4	4.00	10.9	9.69	18.5
Mar 2022	1-10	18.1	23.1	13.7	49.5	77.7	27.7	16.0	28.4	5.40	11.9	8.98	19.9
	11-20	12.8	16.6	9.3	51.1	68.3	33.8	18.2	33.9	5.18	11.9	10.2	21.5
	21-31	16.1	21.0	11.3	51.2	76.0	29.8	16.9	27.1	4.40	12.0	10.7	22.3
Apr 2022	1-10	25.0	33.1	14.0	38.2	66.1	10.7	19.7	31.5	7.80	12.9	10.3	23.8
	11-20	21.5	28.5	16.1	48.2	75.2	22.3	22.4	33.7	12.5	12.9	9.39	22.6
	21-30	23.3	30.2	15.1	44.9	76.9	18.7	14.3	26.3	3.00	13.0	12.2	26.6
May	1-10	23.7	29.6	16.8	41.1	69.3	18.0	17.6	28.9	9.00	13.7	12.1	27.6
Mean	148	17.2	21.9	12.3	53.0	75.6	32.2	15.5	28.0	4.70	11.6	9.0	18.5

T_{mean}, T_{min}, T_{max} are the means, minimum and maximum air temperature, RH_{mean}, RH_{min}, RH_{max} are the the means, minimum and maximum relative humidity, U_{mean}, U_d, Un are the mean, day, and night of wind speed, N and n are the maximum and the average sunshine hours respectively and Rs is the average solar radiation.

Table 3. Effects of foliar potassium application as drought mitigation on some growth parameters of wheat plants grown on field under different irrigation treatments.

% From RAW	Control	$\%K_2O$ - K_2SO_4			Mean	$\%K_2O$ - K_2SiO_3			Mean
	0	0.5	1	2	K_2SO_4	0.5	1	2	K_2SiO_3
Shoot length – cm									
80	86.5A	83.5c-f	87.0ab	79.2f	83.2BC	88.5a	86.0a-d	86.1a-d	86.9A
60	86.6A	86.3a-c	85.6a-d	83.5c-f	85.1AB	81.4f	82.0ef	85.0b-e	82.8C
40	85.7AB	87.0ab	85.9a-d	83.5c-f	85.4AB	84.4b-f	83.4b-f	82.9d-f	83.6BC
Shoot water content - %									
80	67.7AB	66.8a	64.7a-d	62.8cd	64.8BC	65.0a-d	66.7ab	63.5b-d	65.1A-C
60	63.8C	62.4d	63.7a-d	64.5a-d	63.5C	62.1d	62.7cd	62.5cd	62.4C
40	66.6AB	65.0a-d	66.6ab	64.0a-d	65.2AC	64.0a-d	65.6a-c	64.2a-d	64.6BC
Shoot dry weight - g/plant									
80	2.90BC	3.41b	3.30bc	3.11bc	3.27AB	3.41b	3.11bc	3.48ab	3.33AB
60	3.38AB	3.52ab	3.12bc	3.39b	3.34AB	3.14bc	3.94a	3.32bc	3.32AB
40	3.85C	3.61ab	3.32bc	3.31bc	3.41A	3.36bc	3.64b	3.93a	3.58A

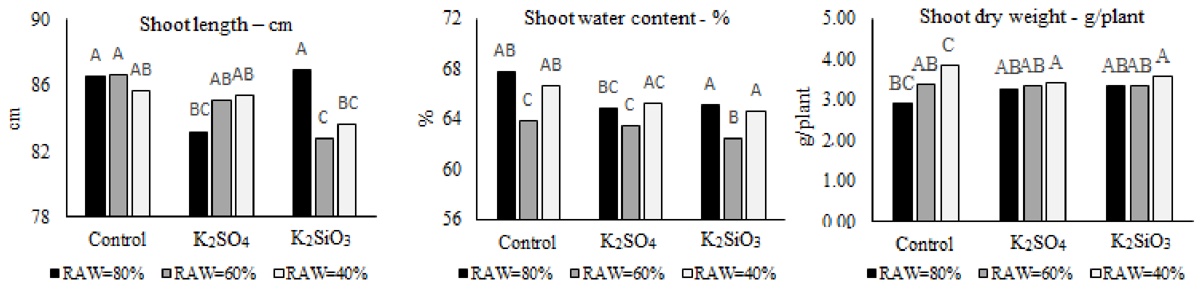

Fig. 1. Effects of foliar potassium application as drought mitigation on some growth parameters of wheat plants grown under different irrigation treatments.

3.3. Effects of foliar potassium on wheat water use, grain yield and water use efficiency

Data in **Table 4** and **Fig. 2** show the effects of foliar potassium applications either as K_2SO_4 or K_2SiO_3 at different concentrations as drought mitigation on water use, grain yield and water use efficiency in kg/m^3 under the different drought treatments. Results revealed that the decrease in wheat water use was highly compatible with the reduction in irrigation water treatments as from 80 to 40 % RAW. There were no significant differences between this positive mitigation effects on wheat water use when using K_2O-K_2SO_4 or K_2O-K_2SO_4. However, foliar potassium treatments, either in terms of sources or concentrations, relatively increased wheat water use by about 111 and 117 and 114 % for the foliar application of K_2O-K_2SO_4 and 120, 120 and 117% for the foliar application of K_2O- K_2SiO_3 at concentration treatments of 0.5, 1.0, and 2% respectively relative to control treatment = 100. It has been observed by Wang et al. (2021) that drought mitigation has beneficial effects including increasing crop yield, limiting abiotic stresses, increasing drought tolerance.

Table 4. Effects of foliar potassium application as drought mitigation on water use efficiency of wheat plants grown under different irrigation treatments.

% From RAW	Control	%K_2O - K_2SO_4			Mean	%K_2O - K_2SiO_3			Mean
	0	0.5	1	2	K_2SO_4	0.5	1	2	K_2SiO_3
Water use - m^3/Fed									
80	1484A	1484a	1484a	1484a	1484A	1484a	1484a	1484a	1484A
60	1285B	1285b	1285b	1285b	1285B	1285b	1285b	1285b	1285B
40	1079C	1079c	1079c	1079c	1079C	1079c	1079c	1079c	1079C
Grain yield - Ton/Fed									
80	2.85BC	2.89b-e	3.26ab	3.25a-c	3.13A	3.31a	3.31a	3.26ab	3.29A
60	2.63CD	3.14a-d	3.12a-d	2.87c-e	3.04AB	3.18ac	3.14ab	2.87c-e	3.06AB
40	2.16E	2.48f	2.58ef	2.58ef	2.55D	2. 72ef	2.71ef	2.77d-f	2.73CD
Water use efficiency - kg/m^3									
80	1.92E	1.95e	2.20de	2.19de	2.11CD	2.23cd	2.23cd	2.20de	2.22BC
60	2.04C-E	2.44a-d	2.43cd	2.24cd	2.37AB	2.47a-d	2.44a-d	2.24b-d	2.38AB
40	2.01DE	2.29a-d	2.39a-d	2.39a-d	2.36AB	2.52ab	2.51ac	2. 57a	2.53A

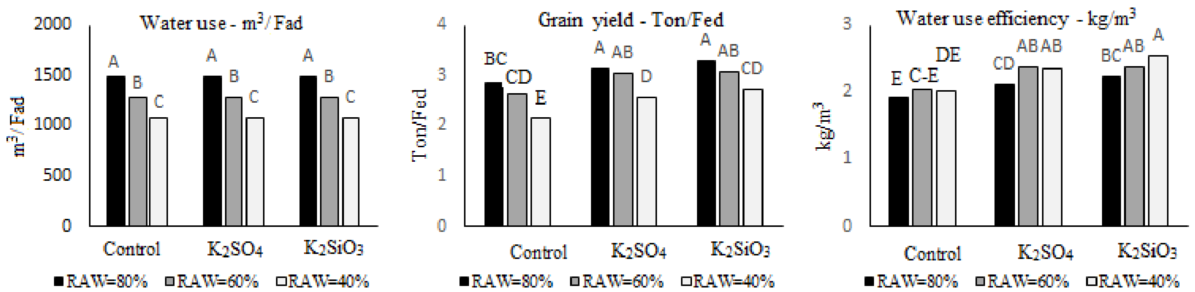

Fig. 2. Effects of foliar potassium application as drought mitigation on water use efficiency and grain yield of wheat plants grown under different irrigation treatments.

Under control treatment (without any addition of K_2O), the grain yield of wheat plants decreased at rates not identical to the decrease in irrigation rates but decreased only about 2.63 (92.3%) and 2.17 Ton/Fed (76.1%) with the reduction in irrigation water from 80% to 60 and 40% RAW respectively.

The foliar application of potassium either in forms of K_2SO_4 or K_2SiO_3 at the different tested concentrations increased the grain production per unit of water use, as shown by the results of calculating the water use efficiency (WUE). Where WUE reached about 2.23 kg/m^3 (112%), 2.34 kg/m^3 (118%) and 2.27 kg/m^3 (114) for K_2SO_4 and 2.41 kg/m^3 (121%), 2.39 kg/m^3 (120%) and 2.33 kg/m^3 (117%) for K_2SiO_3 at concentrations of 0.5, 1 and 2% K_2O respectively compared to 1.99 kg/m^3 (100%) for the control treatment (**Table 4**). However, potassium is an essential nutrient for growth with maintaining cell turgor and regulating the water content plant cells (Rengel and Damon 2008). It could be observed that the positive mitigation effects on wheat grain yield, wheat water use and water use efficiency was more pronounced for potassium silicate (K_2SiO_3) than for potassium sulfate (K_2SO_4). These results are in agreement with that observed by Gong et al. (2003) who find that Si promotes the plant growth by modulating the nutrient uptake and photo-hormone levels and alleviating plant stress levels.

Data in **Table 4** indicated that the WUE markedly increased relative to control value equal 100 by about 114%, and 119% for 2% K_2O-K_2SO_4 and 2% K_2O-K_2SiO_3 respectively. However, the positive mitigation effects on wheat grain yield and WUE was more pronounced for using K_2O-K_2SO_4 (118 and 118%) than K_2O-K_2SiO_3 (110 and 111%) respectively. It has been observed by Wang et al. (2021) that drought mitigation has beneficial effects including increasing crop yield, limiting abiotic stresses, increasing drought tolerance. These results demonstrate the beneficial effects of K_2O in terms of mitigating the negative effects of drought stress on plants by its role in maintaining optimal water relations under drought stress conditions, which in turn support various physiological processes to enhance plant tolerance to drought stress; none of this is due to the nutritive role of K_2O (Cakmak, 2005).

Data in **Table 4** show the effects of foliar application of potassium on wheat grain yield and water use efficiency of wheat plants grown on field under different irrigation treatments. In general, results indicated that the wheat water use consequently decrease with decreasing irrigation water treatment from 80 to 40% of RAW. These decreases were only about 13 and 14% relative with the planned reduction in irrigation water of about 20% for 80-60% and 60-40% RAW irrigation treatments. These differences may be ascribed to the positive effect of foliar potassium applications. Zengin et al. (2009) reported that potassium supply plays an important role in regulating osmotic potential, increasing water uptake ability and avoiding K^+ depletion. In addition, the Si as a co-ion is a valuable nutrient that provides excellent benefits at various growth stages, mainly when there is less moisture (Kovács et al., 2022). Also, the metabolism of SO_4 as a co-ion can form the various defensive compounds (phytochelatins, methionine, glutathione and cysteine) that enhance the plant's strength to resist abiotic stress (Honsel et al., 2012).

Concerning wheat grain yield and water use efficiency under field experiment, Results in **Table 4** indicated that the irrigation treatment 80, 60 and 40 had a little effect on wheat grain yield. While the foliar applications of potassium significantly increased wheat grain yield by about 114% for K_2SO_4 and 119% for K_2SiO_3 relative to 100% for control treatment.

Results in **Table 4** revealed that the WUE increased by about 10 and 13% for irrigation treatments of 60 and 40 %RAW respectively. Regarding the response of wheat grain yield to potassium foliar applications, data in **Table 4** indicated a significant increase in WUE reaches to 115% for K_2SO_4 and 119% for K_2SiO_3 relative to 100% for the control treatment. These increases may be attributed to the positive effects of foliar K_2O applications of both wheat water use and grain yield. The superior positive effects of K_2SiO_3 over K_2SO_4 may be due to the expected dual positive effects of both potassium and silicate on improving the water condition of plants, especially in terms of absorption, transportation and the resistance to loss under drought stress (Akram, et al. 2016).

The positive effects of foliar potassium application on wheat grain yield and water use efficiency may attributed to the effects of potassium in improving the ability of plant to tolerate drought stress by minimizing its negative effects on plant and enhancing the uptake and translocation of water to make a balance (Adhikari et al. 2019). However, it well known that potassium has an actively role in opening and closing of stomata so under limited moisture condition. These results are in agreement with that obtained by Ahmad et al. (2019). They showed that the foliar applications of potassium significantly improved the morphological as well as biochemical characteristics of wheat when grown in the presence as well as absence of drought stress condition. Chlorophyll contents of leaf were enhanced up to a level where radiation use efficiency of the wheat was optimum. They showed that the foliar application of potassium is a high value approach to alleviate the drought stress effects on wheat to enhance the yield.

3.4. Effects of foliar K_2O applications on wheat shoot nutrient contents

Data in **Table 5** and **Fig. 3** show the effects of foliar potassium application as drought mitigation on N, P and K contents in wheat shoots grown on field under different irrigation treatments. It could be observed a slight increase in nitrogen contents in wheat shoots. This increase was more pronounced for the foliar applications of K_2O-K_2SiO_3 than K_2O-K_2SO_4 This increase may be due to the presence of K in the K-silicate solution, which has a significant role in scaling of roots of sugar beet, posing a potential for increasing yield by adjusting K fertilizer recommendation in the study area (Ali et al. 2019; Merwad, 2017).

The foliar applications of potassium had no effects on phosphorus contents in wheat shoots. The foliar application of K_2SiO_3 increased N content in shoots of wheat plant about 104 and 112% for the treatments of K_2SO_4 and K_2SiO_3 respectively relative to 100% for control treatment (foliar spray without K_2O). These results reflect the positive effect of potassium foliar applications on N content in drought stressed plants may be due to improve the root system and consequently water balance of wheat plant grown under such drought stress conditions Similar results were obtained for Sugar Beet by Ali et al. (2019) and Ali, (2017). However, the foliar applications of potassium either in sulfate or silicate forms had no significant effects on phosphorus content in shoots of wheat plants.

Results in **Table 5** clearly indicated that the foliar applications of potassium increased potassium content in wheat shoots with increasing K_2O concentration in the foliar applications. These increases relative to control value equal 100 were about 107, 112 and 125% for K_2O-K_2SO_4 and 112, 116 and 127 for the applications of K_2O in the form of K_2SiO_3 at concentrations of 0.5, 1.0 and 2.0% respectively. The increase in K content in wheat shoots may ascribed to the increase in K_2O concentration in the foliar application treatments. According to Cuong et al. (2017), the application of K_2SiO_3 has a positive impact on almost all the aspects such as availability, assimilation, and uptake of N, P, and K in rice crop. However, He et al. (2014) demonstrated that drought stress decreases the concentration of nitrogen (N) and phosphorus (P) in plant tissue. In addition, several studies have shown that drought can decrease nutrient uptake from soil (Sardans and Peñuelas 2012). Decreases in nutrient uptake during drought stress may occur for several reasons, including the reduction in translocation and nutrient supply through mineralization (Sanaullah et al. 2012).

Table 5. Effects of foliar potassium application as drought mitigation on N, P and K contents in wheat shoots grown on field under different irrigation treatments.

% From RAW	Control	%K_2O - K_2SO_4			Mean	%K_2O - K_2SiO_3			Mean
	0	0.5	1	2	K_2SO_4	0.5	1	2	K_2SiO_3
Nitrogen content in wheat shoots - %									
80	3.47A	2.26cd	3.42bc	4.13a	3.27A	3.51bc	3.53bc	3.86ab	3.63A
60	3.06B	2.66e	2.88df	2.86de	2.80B	3.50bc	3.30cd	3.41b-e	3.40A
40	3.01B	3.50bc	3.29cd	3.64a-c	3.48A	3.75a-c	3.62bc	3.59bc	3.65A
Phosphorus content in wheat shoots - %									
80	0.27B	0.29a	0.32a	0.31a	0.31AB	0.31a	0.28a	0.32a	0.30AB
60	0.32A	0.31a	0.29a	0.31a	0.31AB	0.31a	0.31a	0.30a	0.31A
40	0.32A	0.31a	0.32a	0.33a	0.32A	0.32a	0.31a	0.29a	0.31A
Potassium content in wheat shoots - %									
80	3.98D	4.30de	4.53c	5.08a	4.64AB	4.43c-e	4.58c	5.07a	4.69A
60	3.71E	3.96f	4.32de	4.61c	4.30C	4.26e	4.50cd	4.85b	4.54B
40	3.49F	3.76fg	3.72g	4.24e	3.91D	3.79fg	3.91fg	4.32de	4.01D

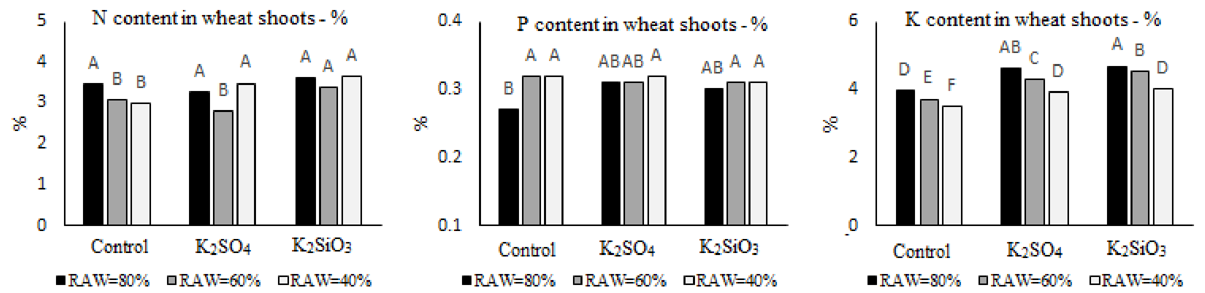

Fig. 3. Effects of foliar potassium application as drought mitigation on N, P and K contents in wheat shoots grown under different irrigation treatments.

Conclusion

From the aforementioned results, it could be concluded that the foliar K_2O application may act positively as drought stress mitigation particularly when applied as potassium silicate (K_2SiO_3) in concentrations ranged between 1-2% K_2O in the foliar solution at the beginning of emergence stage, tillering stage and flowering stage of winter wheat. The results obtained from this research may be considered useful in mitigating the negative effects of climatic changes that may lead to a shortage of water resources and thus exposing crops to drought stress. Moreover, the positive effects of foliar potassium application may be useful to apply on wheat plants grown at the edges of the field where plants usually suffer from drought stress due to exposure of these peripheral areas to many extreme environmental conditions that lead to an increase in the rate of water losses from plant and soil.

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Conflict of interest
Walaa A.M.I. El-Shafei; Manal Mubarak M.; and A. A. Ibrahim and Mona I. Nossier declare that they have no competing interests contribution of Authors: All authors shared in writing, editing and evocate MS and agree to its publication.

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