Research Article

Effect of Foliar Potassium Application on Physiological and Anatomical Traits of Bread Wheat Under Water Stress

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Abstract | An experiment was carried out at the Babylon Extension and Training Center (experimental farm, the Al-Mahnawiyah area) in the Babylon Governorate, Iraq, near the Saddah Al-Hindiyah District Latitude: 32.61° N, Longitude: 44.30° E wheat (*Triticum aestivum* L.) in the winter of 2024-2025 of the growing season. The objectives of the study were to find out the seasonal water needs of wheat production under irrigation and also to assess foliar potassium application in reducing water stress and enhancing the yield and its constituents in wheat. The randomized complete block design (RCBD) was used to set up the experiment, and the split-plot arrangement with three replicates was applied. The main plots were provided with four irrigation treatments (different degrees of water stress) that were: S1 (50 percent of the available soil water depletion), S2 (75 percent of the available water depletion), S3 (50 percent of the added irrigation water depletion), and S4 (rainfed treatment: initial irrigation and rainfall). The amount of potassium was sprayed on the leaves at 0, 200 and 300 mg L^{-1} and placed in the subplots. The findings indicated that the S1 irrigation treatment had the best yield and most desirable yield aspects with a mean of 5.01 t ha^{-1} as the average yield of grains. It was however not greatly different than the S2 treatment which had a 4.94 t ha^{-1}. These results suggest that about 25 percent of irrigation water (which is equivalent to about 74 mm per season) can be conserved without great loss in yield such that more lands can be expanded on cultivation. The S4 treatment, on the other hand, had the greatest proportions of soluble sugars in the flag leaf (17.29 percent) and the amount of vitamin C (62.58mg 100g-1 dry matter). Foliar application of 300 mg L^{-1} produced the highest outcomes in most of the examined traits, specifically grain yield and water use efficiency with average value of 4.58 t ha^{-1} and 2.56 kg ha^{-1} mm^{-1}, respectively. Such findings imply that optimized irrigation control coupled with potassium fertilization would enhance the output of wheat and the efficiency of water use in water-limited situations.

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Introduction

Bread wheat (*Triticum aestivum* L.) is a major strategic crop that is important to food security in the world. It is the first largest in cultivated area and production among cereal crops, and has received majority of agricultural researches and studies due to the dire nature of its demand owing to the gradual rise in population (FAO, 2018). It should thus do everything possible to boost the yield of this crop, considering the water shortage in Iraq. This scarcity has been occasioned by environmental issues, especially the high amounts of air pollution, such as CO 2, and temperature increases in addition to low rainfall. In addition, the situation of water resources monopolization of the neighboring states and the absence of modern irrigation technologies, as well as long-term strategic planning, also threatens wheat production, particularly in the central and southern parts of Iraq, where modern irrigation systems are used. Soil water is among the most crucial factors of wheat production especially in the arid and semi-arid parts of the world that experience low and invariable yearly rainfall (Al-Dulaimi, 2024a). Thus there is an urgent need to... The water scarcity will adversely affect the people, but it is possible to fight this problem using field techniques and practices based on scientific researches. These involve proper estimation of the water demand of crops to enhance water utilization according to the real demands and hence serving to cultivate the more farmlands, particularly in the areas with scarce supplies of water (Abdelraouf *et al*., 2021). The amount of water within the sources is reducing and managing water and water conservation is required to ensure that the maximum production is reached by using minimum water. Also, there is the use of potassium that is used in the physiological processes of plants and this decreases the water consumed (Khan *et al*., 2022). This is essential in reducing water wastedness. Potassium is one of the major nutrients necessary to large amounts of plants to support important physiological processes unsupported by other elements. Photosynthesis should be highly efficient in conditions of water scarcity. Potassium is involved in raising osmotic pressure in the cells and the opening and closing of stomata. It also triggers the transporting and storing of manufactured materials that are in leaves to their storage places in the fruit. More so, it plays the role of being a pump to enhance the intake of nitrogen in the plant that is necessary in the production of protein. Potassium also aids in promoting growth of roots. These all enhance the adaptation to drought and thirst of the plant in water-stressed situations (Hasanuzzaman *et al*., 2018). This research had the following objectives:

To evaluate the effect of water stress levels on wheat yield. To assess the role of foliar potassium in improving drought tolerance and water use efficiency.

Materials and Methods

The experiment was done on the 2024-2025 winter growing season in Babylon Governorate/Sadda al-Hindiya District, in the experimental field of the demonstration farm at the al-Mahnawiya area, which is part of the Babylon Training and Extension Center, in Babylon, in the latitude of 32.61° N and longitude of 44.30° E above sea level. Two factors were incorporated in the study. The former factor was composed of four water stress levels, 50 percent of the available water (control treatment), 75 percent and 50 percent of the added water (control treatment), and the rainfed treatment (first irrigation + rainfall). These aspects were given the primary plots and were coded S1, S2, S3 and S4, respectively. Table 1 is the water treatment of the water consumption in the season above. The second one was a combination of three levels of potassium concentrations (0, 200, and 300 mg L^{-1}) sprayed on the foliage. The spray treatments were sprayed on the secondary plots and barriers were employed. Spray two times to keep the treatments apart in the spraying process: in the start of elongation and in the start of flowering. This counterbalances the water source (vegetative parts) and the water source (grains).

Table 1: *Water consumption treatments for the 2024-2025 agricultural season*

Number of irrigations: S1	(50% of available water) S2	(75% S1) S3	(50% S1) S4	(Germination irrigation + rainfall)
1	67	67	67	67
2	37	27.75	18.5	-
3	37	27.75	18.5	-
4	37	27.75	18.5	-
5	37	27.75	18.5	-
6	37	27.75	18.5	-
7	37	27.75	18.5	-
8	37	27.75	18.5	-
9	37	27.75	18.5	-
Total depth of added water (mm)	363	289	215	67
Rainwater depth (mm)	85.67	85.67	85.67	85.67
Total water consumption (mm)	448.67	374.67	300.67	152.67

Random sample of the soil was collected at

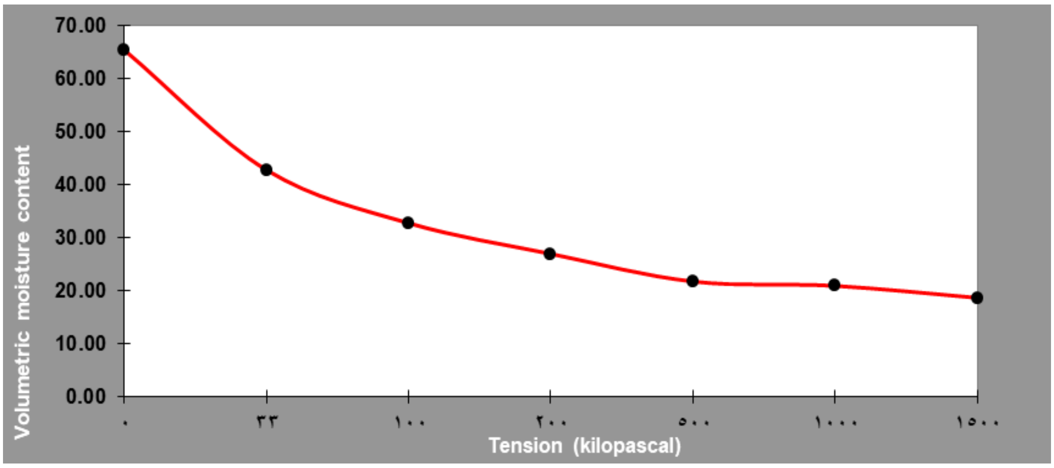

Figure 1: *Soil moisture characteristic curve*

various sites and depths (0-30 cm) Samples , fined and sieved using a 2 mm sieve. The physical and chemical properties of the soil were studied using a homogenous sample. A number of random irrigation water samples were also collected, mixed well and one sample collected with the same intention. Table 2. The connection between the structural tension of the sieved soil sample, and the water content of the same was established to determine the water-holding capacity of the soil. It was done with different tensions (33, 100, 200, 500, 1000, and 1500 kPa) and the relationship was graphically illustrated in the moisture content curve (Figure 1) based on the study parameters, the quantities of water to be added were calculated. Its samples were examined in the laboratories of University of Baghdad/Department of Soil and Water.

Table 2: *Some physical and chemical properties*

		Soil	Water
ECe		1.7	0.82
pH level		7.6	7.3
	N Available	25.33	12.6
	P Available	7.2	4.2
	K Available	205	7.3
OM		1.4	-
	Clay	31	-
	Silt	19	-
	Sand	50	-
Bulk density Mg m^{-3}	1.33		
FC	0.432		
PWP	0.223		
AW	0.204		

The experimental land was plowed twice at right angles with a moldboard plow and the smoothing procedure was done with the use of disc harrows. The plots were then divided and the leveling process was done. The area of the plot was 2 × 3 = 6 m^2. The soil preparation during the process of planting included the addition of phosphate fertilizer as triple superphosphate (45% P2O5) 80 kg.ha^{-1} (José *et al*., 2016). The nitrogen source was urea (N 46) in three equal portions, the first portion added at the beginning of the emergence stage, the second portion at the beginning of the tillering stage, and the last portion at the flowering stage (50%), at a level of 120 kg.ha^{-1} (Neel Ratan *et al*., 2016).

Method for measuring soil moisture content

It was done by placing the pieces of gypsum, which had been calibrated by the relationship between the weighted moisture content and the reading of the resistivity when in kiloohms into the field at a depth of 30 cm (irrigation depth) of the soil. The calibration curve is depicted in Figure 2. The gravimetric method was applied by sampling the soil with ochre one day prior to and two days subsequent to irrigation with the depth of 30 cm. These were Wet weight samples in aluminum. These were dried in an oven at 105C after 24 hrs and weight determined again to find the amount of moisture in the product. The control parameters were monitored using tensiometers to measure the depletion of moisture. The content of moisture was determined based on the equation (Hillel, 1980).

$$(PW) = \frac{MW - DW}{DW} \times 100$$

where:

- PW % = Moisture content based on dry weight

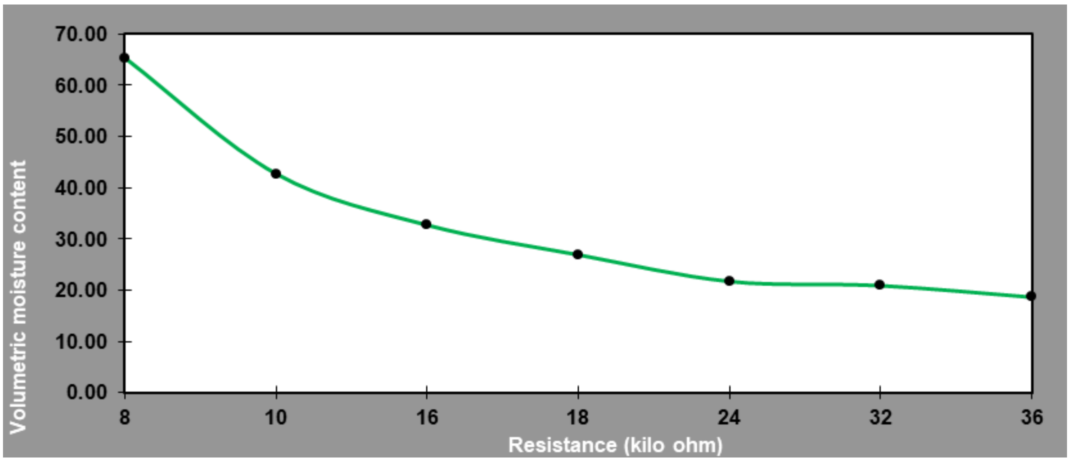

Figure 2: *The relationship between the soil moisture percentage and the resistance (kilo ohms)*

- MW = Wet weight (g)
- DW = Dry weight (g)

Volumetric moisture content was calculated using the following equation (Zein, 2002):

$$Qv = Qw\, \partial b$$

Where:
- Qv = Volumetric moisture content.
- Qw = Weight moisture content.
- ∂b= Apparent density of soil (mg/m^3).

Irrigation, water quantity calculations, and agricultural operations

Soil samples were taken to estimate moisture content before each irrigation using the gravimetric method, to a depth of 30 cm. Plants were irrigated when 50% of the available water was depleted, as monitored in the control treatment S1 and according to the moisture description curve (Figure 1). Irrigation was carried out immediately after sowing, with the planting date set for November 29, 2024. Irrigation continued using plastic pipes based on the depletion of the specified moisture content, which was determined by replenishing the soil to field capacity, according to the following equation (Allen *et al*., 1998):

$$d= (\theta f.c - \theta w)D$$

Where:
- d: Depth of added irrigation water (mm)
- θf.c: Volumetric moisture at field capacity (cm^3 cm^3)
- θw: Volumetric moisture before irrigation (cm^3 cm^3)
- D: Root system depth (mm)

The Mawada variety was used for cultivation, and weeding was carried out as needed. Harvesting took place after the plants reached full maturity on May 11, 2025. A randomized complete block design (RCBD) was used, with a split-plot arrangement and three replications. Each replication was divided into 12 experimental units, with a 2-meter distance between each replication for irrigation channels and paths. Approximately 0.5 meters were left between experimental units to ensure no overlap between experimental treatments. The plots were laid out with 30 cm between rows, and each plot contained 10 rows, each 2 meters long.

After collecting the data, the ready-made statistical program GenStat V.20 was used according to the method used by Alasidi *et al*., 2019, to analyze the data according to the ANOVA table at a probability level of 0.05, and the means were compared according to the least significant difference test at a probability level of 0.05 (Al-Raoie and Khalaf Allah, 2000).

Characteristic Measurements: - Flag Leaf Area (cm^2): Calculated by length × maximum width × 0.95
- Number of Ears (ears/m^2): Calculated from a 1 m^2 harvested area.
- Number of Grains per Ear (grain/ear)/1: Calculated the average number of grains per ear for a random sample of ten ears per experimental unit.
- Weight of 1000 Grains (g): Calculated by weighing 1000 grains randomly selected from the grain yield of each experimental unit.
- Grain Yield (ton/ha^{-1}): Separated from harvested plants in a 1 m^2 area, converted to kg/ha^{-1}, weighed, and returned to the yield calculation. - Actual Water Consumption (ETA): The water balance equation was used to calculate the actual water consumption of

the crop (Allen *et al.*, 1998):

$$ETA = I + P$$

Where:
- ETA: Actual water consumption
- I: Depth of applied irrigation water (mm)
- P: Depth of rainwater (mm)

- Water Efficiency for Grain Yield (WUE) (kg ha^{-1} m^3 - water): Calculated from grain yield / depth of applied water (Ehdaie and Waines, 1993)

- Relative Water Content in Science Leaves (%): Estimated according to the following equation:

$$R.W.C = \frac{FW - Dw}{TW - DW} \times 100$$

- WW = Relative Water Content
- FW = Fresh Weight (g)
- DW = Dry Weight (g)
- TW = Plump Weight (g) (Turgid Weight)

Several tender flag leaves were cut and put into nylon bags to avoid the loss of moisture. They were cut and weighted and put in 12-14 hours under light and room temperature in distilled water. Blotting of the leaves was then done using blotting paper and weighted to show turgid weight. They were then put in an oven at 85C° until the weight stabilized and the dry weight noted (Barnes and Woolley, 1969).

Soluble Sugars in Flag Leaves (%): The amount of soluble sugars in flags leaves was measured by determining percent of soluble sugars by putting in 0.2g of leaves and determining the absorbance at 490nm using the spectrophotometer as per the procedure of Joslyn, 1970.

Vitamin C levels in flag leaves (mg/100g dry matter): Vitamin C (ascorbic acid) was measured by weighing the amount of leaves 1g of flag leaf and measuring the absorbance of the leaf by a spectrophotometer at a 760nm wavelength, as described by Hussain *et al.*, 2010.

- Xylem vessel diameter and phloem tube diameter (.00m): The histological sections were made by hand where the apex of the flag leaf, which was the full width of the plant, was used. Plant samples were also murdered and placed in formalin acetic acid (FAA) solution. It was based on the principle of taking plant samples, clearing them of the green stain using a bleach solution within several seconds, washing them with several portions of water, staining using safranin, placing them on a glass slide with glycerin, covering the slide, and viewing under a light microscope (Arafa *et al.*, 2009). The leaves were then measured some under histological measurements, i.e. in terms of the xylem vessel diameter and the phloem tube diameter units m.

Results and Discussion

1- Flag Leaf Area (cm^2)

Table 3 indicates that there is a considerable change in flag leaf area (cm^2) with differing quantities of irrigation, addition of potassium, and the combination of the two.

Treatment S2 of irrigation treatment had a much greater flag leaf area of 45.65 cm 2 that was not shown to be significantly different than irrigation treatment S1. The low average of 29.98 cm^2 was, however, obtained with irrigation treatment S4. The negative correlation between the amounts of irrigation and the flag leaf area can be explained by the fact that the water deficit influences the cell growth rate, elongation and division, and the water content reduction (Table 10). This outcome is consistent with the work of Shahid *et al.* (2022), who showed that the flag leaf area reduced as the water stress increased.

Table 3: *Shows the effect of water tension levels and potassium concentrations on the average flag leaf area (cm^2)*

Potassium concentrations (mg/ L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	44.00	44.18	35.57	19.85	35.90
200	46.00	46.00	40.12	35.00	41.78
300	46.74	46.76	40.30	35.09	42.22
Means	45.58	45.65	38.66	29.98	
Sig. (0.05)	tension levels 0.52	potassium concentrations 0.63	Interaction 1.11		

The addition of potassium impacted greatly where the treatment of 300 mg L^{-1} was way higher than the one treated at 200 mg L^{-1}. The no-add treatment had the lowest average of 35.90 cm^2, whereas the average water loss per liter was 42.22 and 41.78 cm 2, respectively. This could be explained by the activity of potassium which enhances the effectiveness of photosynthesis and distribution of its products, as well as the activity in the osmotic regulation, thereby minimizing the water loss. This finding is in line with the results of Hasanuzzaman *et al*. (2018).

As for the interaction between the two factors, combinations S1 and S2 with the addition treatments of 300 and 200 mgL^{-1} respectively were significantly superior, with no significant difference between them compared to combination S4 without the addition, which had the lowest means.

2- Number of spikes (spikes m^{-2})

Table 4 indicates that there is a significant difference between the water stress and potassium additive coefficient of this trait but there was no significant difference in the action of the two.

Table 4: *Shows the effect of water stress levels and potassium concentrations on the average number of spikes (spikes/cm^{-2})*

potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	300.18	300.04	300.00	213.33	278.39
200	319.26	318.22	317.21	230.30	296.25
300	348.50	347.15	345.41	248.70	322.44
Means	322.65	321.80	320.87	230.78	
Sig. (0.05)	tension levels 3.86	potassium concentrations 4.31	Interaction n.s		

The irrigation treatment S1 was far better than the other treatments in this characteristic and its average was 322.65 spikes m^{-2}. It was not significantly different than the irrigation treatments of S2 and S3 which had an average of 321.80 and 320.87 spikes m^{-2} respectively. This is contrary to irrigation treatment S4 that produced the lowest average of 230.78 spikes m^{-2}. This reduction can be explained by the competition between the main stem which is rapidly becoming long and the development of large tillers. The dormancy of these tillers resulted in the reduction of newly formed nutrient supply and they were unable to further grow thereby failing to produce spikes. This outcome is also in line with the work of Liwani (2017).

The table also indicates that the treatment that included potassium addition (300 mg L^{-1}) was the best as it had a mean of 322.44 spikes/m^{-2}, as opposed to the treatment that did not include the use of potassium, which recorded the lowest mean of 278.39 spikes/m^{-2}. This distinctiveness can be explained by the active effect of potassium on the activation of enzymes, especially carbohydrate and starch enzymes, that directly result in the growth of the yield components, such as the spike number (Abdallah *et al*., 2019). However, the interaction between the two factors was non-material.

Table 5: *Shows the effect of water stress levels and potassium concentrations on the average number of grains per spike $^{-1}$ grain)*

potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	51.44	52.31	50.62	30.54	46.23
200	58.29	58.18	57.00	39.14	53.15
300	58.59	58.87	57.83	43.65	54.73
Means	56.11	56.45	55.15	37.78	
Sig. (0.05)	tension levels 4.01	potassium concentrations 1.60	Interaction n.s		

3- Number of grains per spike (grain per spike $^{-1}$):

Table 5 demonstrates that, the parameters of water tension and potassium addition had significant difference between the two characteristic but there was no significant difference between the two parameters when they did not interact.

Irrigation treatment S2 was the best with an average of 56.45 grains per spike $^{-1}$, and was not significantly different to treatment S1 and S3. The mean yield of 37.78 grains per spike $^{-1}$ of treatment S4 was the lowest. This reduction can possibly be explained by the fact that water stress becomes more significant at the later stages of the plant growth because the temperatures start to increase and this affects the development of florets and spikes and can also cause the floret abortions. The given observation is consistent with the findings of Farooq *et al*. (2015), who showed that low grain yield per spike is connected to the presence of irrigation water prior to and during flowering. The table further reveals that the application treatment of potassium 300 mg/L and 200mg/L was better and there was no significant difference in that there was a difference in the treatment of 300 mg/L-

[1] and 200mg/L-1 giving an average of 54.73 and 53.15 grains per spike -1, respectively. This can be explained by the active role of potassium in regulating hormones concerning the formation of the florets, their development, pollination, and fertilization, as compared to the treatment without additives, in which the average was the lowest (46.23 grains per spike-1 grain) (Elmasry and El-Rady, 2024). However, the interaction between the two factors was non-material.

Table 6: *Shows the effect of water stress levels and potassium concentrations on the average weight of 1000 grains (g)*

Potassium concentrations (mg/L1-)	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	39.25	34.37	32.21	29.83	33.91
200	39.25	34.38	32.21	29.84	33.92
300	39.22	34.46	32.25	29.87	33.95
Means	39.24	34.40	32.22	29.85	
Sig. (0.05)	Tension levels 1.48	Potassium concentrations n.s	Interaction n.s		

Table 7: *Shows the effect of water stress levels and potassium concentrations on average grain yield (ton ha-1)*

Potassium concentrations (mg/L1-)	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	4.81	4.74	3.66	1.79	3.75
200	5.00	4.95	4.10	2.56	4.15
300	5.21	5.15	4.72	3.23	4.58
Means	5.01	4.94	4.16	2.53	
Sig. (0.05)	Tension levels 0.19	Potassium concentrations 0.15	Interaction 0.29		

4- Weight of 1000 grains (g):

Table 6 reveals that the water stress treatments had a major difference whereas the addition of potassium and the interference did not exhibit any major difference.

Treatment irrigation S1 had a better average weight of 39.24 (g) as compared to the treatment irrigation S4 with the lowest average weight of 29.85 (g). This reduction can be explained by the adverse impact of water stress on the reduction of the area of flag leaves (Table 3). A smaller portion of the light source (vegetative growth) in turn brings down the light interception meaning the restricting of the significant role of supplying the grains with nutrient and accumulated nutrient through dry matter. This in its turn results in a decrease in the grain size and hence weight (Al-Muaini and Al-Ubaidi, 2018). However, the interaction between the two factors was non-material.

5- Grain Yield (ton ha-1):

Table 7 reveals that there are a significant difference in grain yield in terms of water stress treatment and application of potassium and the interaction between the two.

As the table indicates, irrigation treatment S1 performed better than irrigation treatment S2 with the average yield of 5.01 and 4.94 (ton ha -1) respectively, being lower than that of treatment S4, which had the lowest average yield of 2.53 (ton ha -1). This reduction can be explained by the fact that the interaction between the lack of water and high temperatures during the period of filling grain was decreased (Table 6). Furthermore, the shortage of water resulted in the reduction of the dry matter accumulation which in turn gets converted to the grain and other yield components. These aspects have an adverse effect on the yield (Bandgar *et al*., 2020). It is also indicated in the table that the treatment of 300 mg L-1 potassium application did better, the average yield of 4.58 (ton ha-1) being better than the one of the treatment of 300 mg L-1 potassium application. The average yield in the application was 3.75 tons ha-1. This excellence can be explained by the fact that potassium reduces the adverse impact of water stress to ensure the maintenance of guard cell turgor that leads to water transport and partial stomata closing, as well as, triggers the production of CO_2 and reduces the temperature of the plant. This, subsequently, helps in translocation of photosynthetic products to the fertilized grains (Al-Dulaimi *et al*., 2024b). As for the interaction, the S1 combination with the 300 mg L-1 addition treatment was significantly superior compared to the S4 combination without the addition, which had the lowest average.

6- Total water consumption

Table 8 indicates the amount of water that was applied in the growing season, the number of irrigations, and the total amount of water used by

Table 8: *Irrigation water quantity coefficients, number of irrigations, and total seasonal water consumption*

Irrigation water	Treatments number of Irrigations	Rainwater depth (mm)	Added water depth (mm)	Water consumption depth (mm)	Water Used (m^3/hectare)	Water saved (m^3/hectare)
S_1	9	85.67	363	448.67	4486.7	0
S_2	9	85.67	289	374.67	3746.7	740
S_3	9	85.67	215	300.67	3006.7	740
S_4	1	85.67	67	152.67	1526.7	1480

the grower. The amount of water absorbed was as 448.67, 374.67, 300. 67 and 152.67mm in the cases of irrigation treatments S1, S2, S3 and S4 respectively. We find that the values of water consumption are lower because of the lower water quantities in irrigation. This notwithstanding, the treatment S2 of irrigation produced a yield of grains in Table 7 which was not significantly different with S1. This had the benefit of the potential to save around 25% of the total irrigation demand, which translated to a water conservation of 74 mm of season 1. This water conservation can be utilized in expanding the piece of land of this crop. The table also reveals that the amount of water that was used in the control treatment was the maximum possible, which is normal considering the fact that the soil was near the field capacity of moisture. This had a positive impact on most of the growth features and yield and also led to an increase in the quantity of water lost by evaporation Hamid and Naser (2020a); Hamid and Naser (2020b).

7-Water use efficiency for grain yield (WUE) (kg ha^{-1} m^3 water)

Table 9 indicates that there are great disparities among water use efficiency in grain yield, interaction among irrigation, potassium foliar application treatments among them.

The irrigation treatment S4 was much better as it had a mean of 3.77 (kg ha^{-1} m^3 water) compared to the irrigation treatment S1 which had the lowest mean score of this characteristic at 1.38 (kg ha $^{-1}$ m^3 water). Such excellence could be explained by the fact that less water was used than in the case of treatment S1 where the maximum level of water was used.

The table also indicates the excellence of the foliar application of 300 mg L^{-1}. The maximum average of water stress level (kg ha^{-1} m^3 water) was 2.56 kg ha -1 m 3 water in the L $^{-1}$ treatment, which was greater than the lowest average of 1.83 kg ha $^{-1}$ m^3 water in the control group. This disparity is explained by the importance of potassium in enhancing plant water status due to its ability to control stomatal opening and closing thus minimizing the transpiration loss and maximizing the water use efficiency (Abdul Mahdi, 2023). As for the interaction between the two factors, the S4 combination with the addition of 300 mg L^{-1} was significantly superior compared to the S1 combination with the addition rate, which had the lowest averages.

Table 9: *Shows the effect of water stress levels and potassium concentrations on water use efficiency (kg ha^{-1} mm^{-1})*

Potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	1.32	1.64	1.70	2.68	1.83
200	1.38	1.71	1.91	3.83	2.20
300	1.43	1.78	2.20	4.82	2.56
Means	1.38	1.71	1.93	3.77	
Sig. (0.05)	Tension levels 0.32	Potassium concentrations 0.09	Interaction 0.34		

8- Relative water content in leaf (%)

Table 10 indicates that there are high disparities in the effects of irrigation treatments and potassium supplementation on this trait and the interaction between them.

Water stress led to a reduction in the relative water content. The highest average was of this trait in irrigation treatment S1 with 80.10% not significantly different with irrigation treatment S2 with 78.82% in comparison with the rainfed treatment S4 with the lowest average of 61.87%. Water stress might cause a reduction in the water stress of plants as this could be explained by reduction of soil water potential, and hence, a reduction in plants water uptake and thus the reduction in tissue water content. This subsequently caused stomatal closure, and reduced rate of growth. Additionally, water evaporation through the leaves because of heat led to the condition of disequilibrium between absorption and transpiration, and such a state produced adverse effects on the water state of the plant (Chaouachi *et al*., 2023).

Table 10: *Shows the effect of water stress levels and potassium concentrations on the relative water content of flag leaves (%)*

Potassium concentrations (mg/ L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	77.32	74.65	61.03	60.32	68.33
200	80.54	79.88	71.29	61.47	73.30
300	82.45	81.93	76.47	63.81	76.17
Means	80.10	78.82	69.60	61.87	
Sig. (0.05)	Tension levels 1.47	Potassium concentrations 1.38	Interaction 2.54		

Table 11: *Shows the effect of water stress levels and potassium concentrations on soluble sugars in flag leaves (%)*

Potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	12.85	14.96	16.98	16.83	15.41
200	12.87	15.03	16.99	17.45	15.58
300	12.91	15.08	17.48	17.57	15.76
Means	12.87	15.02	17.15	17.29	
Sig. (0.05)	Tension levels 0.58	Potassium concentrations 0.14	Interaction 0.60		

The superiority of the 300 mg L^{-1} supplementation treatment is also very high as indicated in the table. The mean concentration of potassium in liter-1 was 76.17% with 68.33% corresponding to no potassium application. This advantage can be explained by the fact that potassium is very important in regulating the water usage by the plant and the rates of transpiration by regulating the opening and closing of stomata. This keeps the cell swell and regulates the water balance in the plant tissue. Furthermore, potassium controls the water potential of the leaf cells by enhancing the movement of the xylem into the leaf and thus the water content in the leaf increases (Al-Rubaie, 2022). As for the interaction, combinations S1 and S2 were superior, with no significant difference between them when 300 mg L^{-1} was added, compared to combination S4 when no addition was made, which had the lowest averages.

9- Soluble sugars in science leaves (%)

Table 11 indicates that there are great changes in soluble sugar content of science leaves under irrigation and potassium spray treatments as well as the combination of both.

Soluble sugars in Science Soluble sugars in leaves of flag plant were found to increase after water stress. The treatment that gave the highest average solvent sugar percentage (S4) of 17.29% was not significantly different than the treatment of the irrigated treatment (S3) with 17.15% average as compared to the control treatment (S1), where the average was lowest at 12.87%. This could be explained by the fact that the activity of the amylase enzyme is more active in the presence of a water stress. Amylase is the one that enhances the rate at which starch breaks down, hence causing an elevation in the levels of sugars. Sugars are involved in the control of osmotic potential in cells by stopping cell membranes against damage and preserving their integrity and stabilizing the activity of proteins and enzymes. It is also among the defence mechanisms of this plant to sustain water balance when there is water stress (Chachar *et al*., 2016).

It is also indicated in the table that the potassium foliar spray treatment (300 mg L^{-1}) was very superior. The mean of the potassium in the L-1 plant was 15.76%, the lowest mean of 15.41% on the same, and no potassium was added. This growth can be explained by the fact that potassium can tremendously boost the transportation and storage of sugars particularly in the post flowering and early-fruit-setting periods, thereby maximizing the size and quality of fruits. As an enzyme activator, potassium increases and speeds up the process of photosynthesis (sugar formation) and controls its transportation (Al-Rubaie, 2021). As for the interaction between the two factors, combination S4 was significantly superior when treated with the addition of 300 mg L^{-1} compared to combination S1 when no addition was made, which gave the lowest averages.

10- Vitamin C content in flag leaves (mg per 100 g^{-1} dry matter)

Table 12 indicates that vitamin C content differs significantly in flag leaves when the leaf is irrigated and level of potassium sprays applied. The interaction effect between these treatments did not show any significant differences.

The table reveals that the rate of vitamin C concentration in the leaves of the flag plant increases with the water stress. Rain-fed treatment S4 had a great performance compared to treatment S3 where the treatment had an average of 62.58 and 61.80 mg per 100 g of dry matter respectively. The lowest average of this characteristic was obtained in treatment S1 (the control) and is 56.35 mg per 100 g^{-1} dry matter. Vitamin C is regarded as the initial defense of non-enzymatic antioxidants and has the capability to counteract adverse reactive oxygen species (ROS) especially the superoxide radicals, hydroxyl radicals, and singlet.oxygen, and dismantling hydrogen peroxide to water by use of enzyme ascorbate peroxidex (Gratao *et al*., 2005).

It is also seen in the table that the advantage of the 300 mg L^{-1} spray treatment has a significant mean 60.77 mg per 100 g^{-1} dry matter as compared to the no-apply treatment which had the least mean of 58.61 mg per 100 g^{-1} dry matter. This can be explained by the fact that potassium can increase physiological activity of plant cells, and especially enzymatic reactions related to oxidation-reduction processes, which are associated with the increased production of antioxidant compounds, including vitamin C (Al-Rubaie, 2021). The interaction between the two factors was not significant.

Table 12: *Shows the effect of water stress levels and potassium concentrations on vitamin C content in flag leaves (mg per 100 g^{-1} dry matter)*

Potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	55.02	57.49	60.14	61.79	58.61
200	56.52	59.15	62.10	62.91	60.17
300	57.52	59.37	63.15	63.04	60.77
Means	56.35	58.67	61.80	62.58	
Sig. (0.05)	Tension levels 1.60	Potassium concentrations 0.60	Interaction n.s		

11- Xylem vessel diameter and phloem tube diameter (μm):

The Table 13 and Table 14 indicate that the irrigation treatments, potassium supplementation and the potassium interaction had a significant effect on this trait.

When there are heightened water tension, we also find that the diameter of the xylem vessels and phloem tubes are reduced as a result of the mechanical pressure. This narrowing of the diameter relative to their normal condition is to guarantee uninterrupted flow of water. This was seen in the treatment of S4, where the average diameters were the least as they were 49.28 and 76.35 (μm) in the xylem vessel diameter and phloem tube diameter respectively. This is unlike the S1 control treatment, which recorded the largest average diameters namely 62.11 and 82.65 (μm) of the xylem vessel diameter and phloem tube diameter respectively.

Table 13: *Shows the effect of water tension levels and potassium concentrations on the diameter of the wooden vessel (μm)*

Potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	61.34	58.56	56.41	42.19	54.62
200	61.69	58.16	57.49	50.31	56.91
300	63.30	60.83	60.66	55.33	60.03
Means	62.11	59.18	58.18	49.28	
Sig. (0.05)	Tension levels 1.97	Potassium concentrations 0.91	Interaction 2.27		

Table 14: *Shows the effect of water tension levels and potassium concentrations on the diameter of the phloem tube (μm)*

Potassium concentrations (mg/L^{1-})	Water tension levels				Means
	S_1	S_2	S_3	S_4	
0	82.32	80.41	78.20	74.60	78.88
200	82.66	80.66	79.54	76.32	79.79
300	82.96	81.12	79.88	78.13	80.52
Means	82.65	80.73	79.21	76.35	
Sig. (0.05)	Tension levels 0.78	Potassium concentrations 0.46	Interaction 1.00		

According to the table, the potassium spray treatments enhanced the internal anatomical traits of the leaf by raising the diameters of the xylem, as well as the phloem tubes. The treatment that included the addition of 300 mg.L^{-1} was the best where the average of the diameter of xylem vessel and phloem tube was 60.03 and 80.52 (μm), respectively, compared to the treatment that included the addition of 300 $mg.L^{-1}$ as it gave the lowest average of 54.62 and 78.88 (µm) of diameter of xylem vessel and phloem tube, respectively. This is because the effect of potassium on the above anatomical characteristics is realized since potassium influences the structure of leaves and their development. It adds structural stability to the leaves as they are incorporated in the cell walls and has an effect on the development and thickening of tissues. It also helps in augmenting the quantity and thickness of vessels over the bundle sheath and converting the vessels into sclerenchyma cell fibers and this is echoed in the maintenance of the leaf structure, which indirectly leads to a rise in photosynthesis (Soares *et al*., 2012) Al-Juthery *et al*. (2025).

Conclusions and Recommendations

This study demonstrated that foliar application of potassium plays an important role in improving the physiological and anatomical traits of bread wheat under water stress conditions. The results showed that potassium application enhanced key physiological parameters, including chlorophyll content and water status, which contributed to better plant performance under drought conditions.

In addition, potassium treatments improved anatomical characteristics, helping plants maintain structural integrity and adapt to water deficit stress. These improvements were reflected in enhanced growth and yield stability compared to untreated plants.

Overall, foliar potassium application can be considered an effective agronomic practice to mitigate the adverse effects of water stress and improve wheat productivity under arid and semi-arid conditions.

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Novelty Statement

The study highlights the role of foliar potassium application in improving wheat tolerance to water stress under Iraqi condi-tions. It also demonstrates the potential for reducing irrigation water by up to 25% without significant yield loss.

Author's Contribution

Zaman Salah Al-Dulaimi: Designed the study, analyzed data, and wrote the manuscript.
Zainab N.M.A. Al-Zubaidy: Conducted field and laboratory work.
Alaa Ahmed Obaid: Performed statistical analysis.
Maher Nazim Al-Fatlawi: Supervised and revised the manuscript.

Generative AI and AI-assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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