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ARTICLE

Effect of Anti-Transpiration and Potassium on Water Use Efficiency and Water Consumption under Water Stress Conditions to Climate Change Resistance

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ABSTRACT

Climate change impact serious threats to global food security due to changes in water requirements resulting from the variation and instability of the spatial and temporal distribution of rainfall and the lack of water availability. Therefore, our research aims to use anti-transpiration agents that reduce plant water consumption, thus providing adequate amounts of water for agriculture in arid areas. A field experiment was conducted under water stress conditions during the winter seasons 2022–2023 and 2023–2024. The study included three levels of water stress, which are depletion of 40, 55 and 70% of the available water at a depth of 20 cm for the first three irrigations and a depth of 30 cm for the remaining irrigations and for the three treatments in succession. Anti-transpiration was added from different sources, which are kaolin, paraffin wax, silicon and potassium, in addition to the comparison treatment (spraying with water only). The results showed significant differences between the depletion treatments, as the 40% depletion treatment of the available water was significantly superior in most of the characteristics of the crop and its components, as the amount of increase in the grain yield was 62.24 and 64.22% for the two seasons in succession, compared to the 70% depletion treatment of the available water, which gave the lowest averages for all the studied characteristics. The irrigation treatment after depleting 40% of the available water was characterized by the best water use efficiency of 1.60 and 1.44 kg m^{-3} for the two seasons respectively, compared to the treatment of depleting 70% of the available water, which gave the lowest water use efficiency of 1.14 and 1.02 kg m^{-3} for the two seasons respectively. Spraying with anti-transpiration and potassium led to a significant increase in the yield and all its components compared to the comparison treatment (spraying with water only), which gave the lowest averages

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for all the studied traits,as spraying with potassium and kaolin gave a significant increase in most of the studied traits. Also, anti-transpiration and potassium, represented by potassium and kaolin, had a significant effect on water use efficiency, as the increase amount when spraying with potassium was 45.87 and 46.93% for the two seasons respectively compared to the comparison treatment (spraying with water only). As for the actual water consumption, we find an increase in the values of water consumption and the number of irrigations in the comparison treatment (spraying with water only) compared to the anti-transpiration and potassium treatments, as the anti-transpiration and potassium provided water at a depth of 550, 414 and 405 m^3 ha^{-1} for the first season and 615, 375 and 393 m^3 ha^{-1} for the second season for the depletion treatments of 40, 55 and 70% of the available water, respectively, compared to the comparison treatment (spraying with water only). This increase is not small when applied to large areas and providing additional agricultural areas that can be invested. These findings suggest that targeted use of these treatments can effectively mitigate the effects of water stress, improving wheat production and resource efficiency in water-limited environments.

Keywords: Water stress; Anti-transpiration agents; Potassium; Crop water use efficiency; Water consumption

1. Introduction

Water shortage represents the main obstacle to wheat production. In various countries of the world in light of climate changes and the development of the phenomenon of global warming in the world and its impact on the cultivation of all crops, including wheat, in addition to the decrease in rainfall rates and the decline in the amount of flowing water and the subsequent rise in temperatures and the increase in rates of water loss through evaporation - transpiration, as Water stress directly or indirectly affects many growth processes and plant yields, as its effect increases with rising temperatures and within thermal ranges that vary according to the type of plant and the conditions of the region [1,2]. In a study conducted by [3], they showed that the compatibility of plant requirements with climatic conditions, water availability, and environmental conditions of agricultural crops is the most important prerequisite for obtaining high productivity. [4,5] found that changing the sowing or planting date and increasing plant density can reduce the risk of crop failure and compensate for the expected decline in yield caused by climate change in semi-arid and dry sub-humid parts. Here it was necessary to work to improve the tolerance of crops, especially the wheat crop, which It is considered one of the most important sources of food in the world, and the need for it is constantly increasing, so it calls for attention to its cultivation under the available conditions [6].

Anti-transpiration treatments can significantly reduce water loss in agriculture by limiting transpiration through the leaves of crops. This technique helps to conserve water, particularly in arid regions, while maintaining crop yields. Research indicates that anti-transpirants can enhance water use efficiency by creating a protective layer on the leaf surface. However, the effectiveness varies depending on the type of crop and environmental conditions [7]. One of the greatest losses caused by water shortages in various regions is the decrease in yield [8], and this was confirmed by [9] that water stress is one of the most severe abiotic stresses that causes a reduction in grain yield by up to 17–70%. Many ways have been suggested to overcome the problem of water stress, including planning the rate and time of irrigation requirements. Antitranspirants enhance plant water status by lowering the rate of transpiration, but they also decrease CO2 uptake, which in turn reduces the rate of photosynthesis [10]. Chitosan, abiotic agent derived from chitin, is a mildly toxic yet eco-friendly compound that promotes positive responses in crops. It enhances yield, chlorophyll content, and various plant growth parameters, while also inducing strong resistance to drought, salinity, and low-temperature stress, thereby mitigating their adverse effects on cereals [11]. Kaolin, anontoxic and environmentally friendly natural antitranspirant, has been shown to improve growth traits, yield, and its components, and to lessen the negative impacts of water scarcity in wheat [12]. However, kaolin may increase leaf temperature if the plant is not experiencing drought stress [13]. A field study was conducted during the 2019 and 2020 seasons in newly reclaimed land in El-Minia Governorate, Egypt, to evaluate the response of maize crops to three irrigation levels, three plant densities, and three antitranspirant treatments. The experiment was designed using a randomized complete block design (RCBD) with split plots in strips [14].

Another way to confront water stress for suitable means that reduce transpiration rates without affecting the process of carbon metabolism, including the use of anti-transpiration agents, which are chemical substances that are sprayed on the leaves and work to reduce the average transpiration rate and increase the efficiency of water use by creating barriers or... Preventing water loss through a mechanical (physical) or physiological mechanism that does not lead to damage to the leaf after it dries [15], as it has been observed that about 99% of the water that the plant takes from the soil is lost through transpiration, so if transpiration is controlled This helps to achieve an appropriate balance of water, as well as the use of potassium, which is one of the major nutrients and which the wheat plant needs in large quantities for its role in many metabolic and physiological processes, as well as it helps in increasing cell division. It also has a role in withstanding water stress through increased pressure. The osmosis of cells controls the opening and closing of stomata, which prevents the wilting of plants exposed to water stress [16].

This study aims to investigate the role of anti-transpiration and potassium in reducing water consumption, increasing water consumption efficiency, and improving crop characteristics under the influence of water stress. It also aims to manage water under different water stress conditions to demonstrate the possibility of obtaining a high yield with less water consumption. the present study is an attempt to determine water consumption under water stress, using some antitranspirants to reduce water losses by reducing the extent of transpiration in newly reclaimed soil

2. Materials and methods

Two field experiments were carried out during the winter seasons 2022–2023 and 2023–2024 in Babil Governorate/Seddat al-Hindiyya district in the extension farm experiment field in the Al-Mahnawiya area affiliated with the extension training center in Babil, 8 km north of Babil and located within latitude 32.6154N and Length 44.3045E above sea level. A randomized complete block design (RCBD) with a split plot arrangement with three replications was used for both experiments. It included three levels of water depletion, To manage water under different climatic conditions depending on the availability of water quantity which were depletion of 40, 55, and 70% of the available water, and were symbolized as S1, S2, and S3, and occupied the main panels, while anti-transpiration and potassium agents were occupied, which included kaolin at a concentration of 6%, paraffin wax at a concentration of 1%, silicon at a concentration of 15 ml L^{-1}, and potassium at a concentration of 3000 $mg.L^{-1}$. In addition to the comparison treatment (spraying water only) in the secondary plots, the land was prepared and prepared according to followed scientific recommendations, and the field was divided into three sectors, and each sector was divided into panels (experimental units) of 15 experimental units, and 1.5 m intervals were left between the main treatments. The same was true between the replicates to prevent water leakage and 0.75 m between the experimental units.

Some physical and chemical characteristics of the soil of the experimental field were estimated by taking, before planting, samples of undisturbed soil randomly from different locations to a depth of (0–30) cm, after scraping 5 cm of the surface layer of the soil. The samples were mixed well to homogenize them, then they were air-dried, smoothed, and then passed through A sieve with a diameter of 2 mm, for the purpose of conducting some analyzes to determine the physical and chemical properties of the soil. A sample of irrigation water, which was sourced from the river, was also taken for the same purpose, as in **Table 1**.

The relationship between the structural tension of the soil sample and the moisture content was estimated to estimate the soil retention capacity at the tensions (33, 100, 500, 1000, and 1500) kilopascals, through which the available water content of the soil is calculated from the difference between the moisture content at the field capacity (33 kilopascals) and the point Permanent wilting (1500 kPa) as in **Figure 1**.

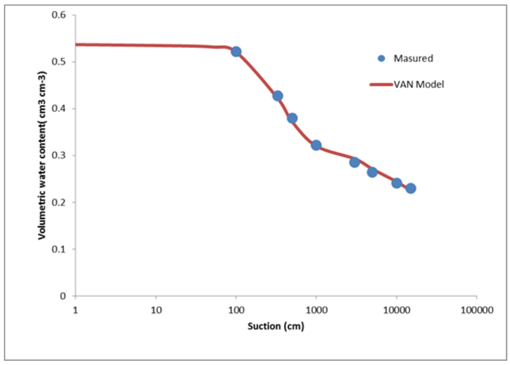

Figure 1. Moisture description curve for the soil used in the study.

3. Method for measuring soil moisture content

The gravimetric method was used to measure the moisture content of the soil by taking soil samples with an Auger one day before irrigation, for two depths (20) from planting to the branching stage ZGs22 and (30) cm from the branching stage to physiological maturity, and they were placed in aluminum cans with a known weight, then They were weighed while wet and then dried in a microwave oven at a temperature of 105°C for 12 minutes after the temperature

Table 1. Some chemical and physical characteristics of field soil before planting.

	Characteristics	Value		Unit
		pH		
1.	Soil	7.9		-
	Water	7.7		-
		EC		
2.	Soil	3		ds.m^{-1}
	Water	2.1		
3.	O.M	0.57		gm.kg^{-1}
4.	Porosity	42		%
5.	Bulk density	1.39		M gm.m^{-3}
		Available K		
6.	Soil	160		ppm
	Water	8.3		ppm
		Available P		
7.	Soil	7.2		ppm
	Water	6.3		ppm
		Available N		
8.	Soil	43.5		ppm
	Water	15.5		ppm
		Sand	5.16	
9.	Soil particles	Silt	60.84	gm.kg^{-1}
		Clay	34	
10.	soil Texture	Silty clay loam		
11.	Water content at F.C	0.428		cm^{-3} cm^{-3}
12.	Water content at PWP	0.23		cm^{-3} cm^{-3}
13.	Available Water	0.198		cm^{-3} cm^{-3}

and drying time were adjusted with the electric oven and according to the method suggested by[17] for drying samples. Then the dry sample was weighed and the moisture content in it was estimated according to the equation Contained in[18].

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

Since:

PW = moisture content based on dry weight

MW = wet weight (g)

DW = dry weight (g)

- The volumetric moisture content was calculated using the following equation:

$$Qv = Qw \times \partial b$$

Since:

Qv = moisture content based on volume.

Qw= Moisture content based on weight.

= Bulk density of soil (megagrams m^{-3}).

3.1 Irrigation and water quantity calculation

Irrigation was done using plastic tubes connected to a fixed-discharge electric pump, and a meter was attached to the tube to measure the water passing through the tube in litres. Equal amounts of water were added to all panels at planting (first irrigation) and within the limits of field capacity to ensure field emergence. The plants were irrigated when the quantities of prepared water mentioned for the treatments were exhausted at a depth of 20 and 30 cm. The depth of the added water was calculated according to the equation[19].

$$d = (\Theta fc - \Theta w) \times D$$

Since:

d: depth of added water (mm).

Θfc: volumetric humidity at field capacity (cm^3 cm^{-3}).

Θw: volumetric humidity before irrigation (cm^3 cm^{-3}).

D: Effective root system depth (cm).

3.2 Grain yield (I-1)

Grains were separated from the sample plants harvested for an area of 1 m^2 from each experimental unit and then converted to tons ha^{-1}.

3.3 Actual water consumption ETa

The actual water consumption of wheat was estimated using the water budget equation[20].

$$\Delta S = (I+P+C) - (ET_a+D+R)$$

Since:

I: Depth of added irrigation water (mm).

P: rainwater depth (mm)

C: Height of water by capillary action (mm) assuming = 0 because the depth of ground water is more than a meter.

ETa: Actual evapotranspiration (mm).

D: Depth of excavation water (mm) assuming = 0. Deep percolation losses equal to zero.

R: Surface runoff (mm) assuming = 0 because the panels are flat and defined by shoulders that do not allow surface runoff to occur.

ΔS: Change in soil moisture storage at the beginning and end of the season = 0 because the moisture content of the soil at the beginning of the season is close to its content at the end of the season, meaning that the water consumption equation becomes as follows:

$$ET_a = I+P$$

Water use efficiency for grain yield (kg m^{-3} water): According to the equation of Ehdaie and Waines, (1993):

$$W.U.Eg = \frac{GY}{ET}$$

Since:

WUEg = Water Use Efficiency (kg m^{-3}).

GY = grain yield (kg ha^{-1}).

ET = total water consumption of the crop (m^3 ha^{-1}).

3.4 Climatic data

Climatic data for the two growing seasons were obtained from the Agricultural Meteorology Center. Babil Governorate—Al-Mahnawiyah Station.

4. Results and discussion

4.1 Actual water consumption ETa

Table 2 shows that the actual water consumption rate (ETa) under the influence of anti-transpiration and potassium differed according to the levels of water depletion, as the depletion treatment (S1) recorded the highest water consumption rates of 350.35 and 404.2 mm season-1 for the two seasons respectively, that is, an average of 377.28 mm season-1. 1 as an average for the two seasons, while the depletion treatment (S3) had the lowest seasonal water consumption values, reaching 304.35 and 346.1 mm season-1 for the two seasons, respectively, meaning an average of 325.23 mm season-1 as an average for the two seasons.

We also notice from the table results that the water consumption values increased in the comparison treatment (spraying distilled water), as the depletion treatment (S1) recorded the highest water consumption rates of 405.35 and 465.7 mm season-1 for the two seasons in succession, meaning an average of 435.53 mm season-1 as an average for the two seasons. While the depletion treatment (S3) had the lowest seasonal water consumption values, reaching 344.85 and 385.4 mm season-1 for the two seasons, respectively, with an average of 365.13 mm season-1 as an average for the two seasons.

We note that water consumption values can be reduced when using anti-transpiration and potassium by a value of 13.37, 9.93, and 10.93% for the depletion treatments S1, S2, and S3, respectively, compared to the comparison treatment (spraying water only) for the two study seasons, meaning that 582% water can be saved. 5,394.5 and 399 m^3ha^{-1} for the depletion treatments mentioned in succession, compared to the comparison treatment (spraying distilled water), and this increase is not small when applying this to large areas. That is, through this increase it is possible to provide additional agricultural areas that can be invested on the one hand, and on the other hand Other, we find an increase in yield when using anti-transpiration agents compared to the control treatment (distilled water).

4.2 Water use efficiency of grain yield (kg m^{-3} water)

Figure 2 and **Figure 3** indicate that there is a significant effect of depletion of available water, anti-transpiration agents, and potassium, and their interaction, on grain yield

Table 2. Actual water consumption (mm) and number of irrigations for depletion treatments for the two growing seasons 2022–2023 and 2023–2024.

Season	depletion level	No. of Irr.	water depth mm	Rain depth mm	Eta mm season-1	Eto mm season-1	Control treatment		
							No. of Irr.	Eta mm season-1	Eta mm season-1
2022–2023	S1	10	245	105.35	350.35	3503.5	12	405.35	4053.5
	S2	9	225.4	105.35	330.75	3307.5	10	372.15	3721.5
	S3	7	199	105.35	304.35	3043.5	8	344.85	3448.5
2023–2024	S1	11	344.7	59.5	404.2	4042	13	465.7	4657
	S2	10	325.1	59.5	384.6	3846	11	422.1	4221
	S3	8	286.6	59.5	346.1	3461	9	385.4	3854

efficiency for the two seasons.

The S1 depletion treatment gave the highest averages for water use efficiency, amounting to 1.60 and 1.44 kg m^{-3} for the two consecutive seasons, compared to the S3 depletion treatment, which had the lowest averages for this characteristic, amounting to 1.14 and 1.02 kg m^{-3} for the two consecutive seasons. The reason for the decrease in water use efficiency with an increase in the level of depletion may be attributed to the fact that water consumption is closely related to the yield and that the water use efficiency is related to the ratio between them, and since the grain yield decreased with an increase in the level of depletion, due to the reduction in the number of spike, the number of grains per spike, and the weight of the grains. Which led to a decrease in grain yield, and this in turn led to a decrease in the efficiency of water use.

The results showed that spraying anti-transpiration agents and potassium had a significant effect in increasing the efficiency of water use, as the potassium spraying treatment was superior with an average of 1.59 and 1.44 kg m^{-3} for the two consecutive seasons, and without a significant difference with the kaolin spraying treatment for the second season, compared to the comparison treatment (spraying water only). Which had the lowest averages for this characteristic, reaching 1.09 and 0.98 kg m^{-3} for the two consecutive seasons. The reason for the increase may be attributed to the role of potassium and kaolin in improving the water condition of the plant, by regulating the process of opening and closing the stomata, as well as the partial closing of the stomata, which reduces the process of water loss through transpiration while maintaining the efficiency of the photosynthesis process, which reflects positively on the efficiency of water use, in addition to the role of Potassium and kaolin increase the root system and then increase the amount of water absorbed, which makes the plant tissue have a balanced water content, which reflects positively on the growth and development of the plant, especially in conditions of water stress, thus maintaining the balance of the yield in these conditions and obtaining high water use efficiency. This result is consistent with what was previously concluded by [21–23], who showed that the efficiency of water use increases in the presence of potassium and the anti-transpiration agent kaolin.

It is noted from the interaction data for the two seasons that there is a significant response to the interaction of anti-transpiration and potassium with the water depletion treatments. The combination of S1 and potassium spray recorded the highest average water use efficiency of 1.75 and 1.55 kg m^{-3} for the two seasons, respectively, compared to an average of 0.81 and 0.60 kg m^{-3} for the two seasons, respectively, at the Combination of depletion treatment S3 and comparison treatment (spraying water only).

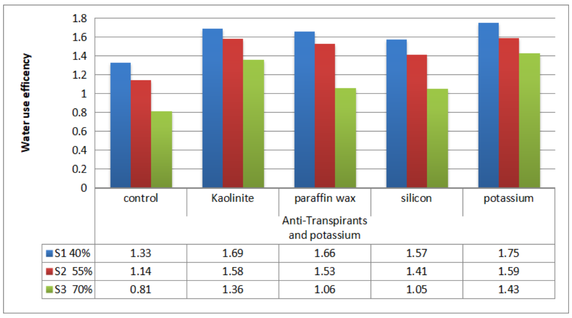

Figure 2. Effect of available water depletion levels, anti-transpiration agents, and potassium, and their interaction, on water use efficiency for grain yield (kg m^{-3}) for seasons 2023–2024.

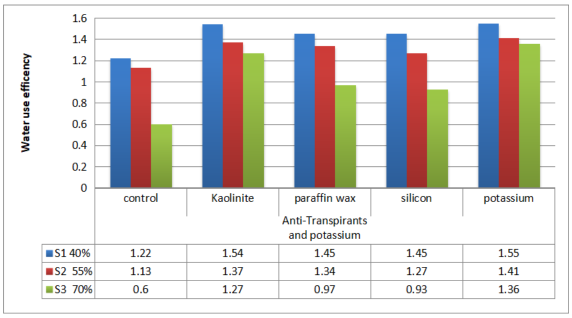

Figure 3. Effect of available water depletion levels, anti-transpiration agents, and potassium, and their interaction, on water use efficiency for grain yield (kg m^{-3}) for seasons 2022–2023.

4.3 Grain yield (ton ha^{-1})

Figure 4 and **Figure 5** indicate that there are significant differences in grain yield for the two seasons due to the effect of depletion of available water, anti-transpiration agents, and potassium and the interaction between them.

The S1 depletion treatment gave the highest average for this characteristic, amounting to 5.63 and 5.83 tons ha^{-1} for the two consecutive seasons, while the S3 depletion treatment gave the lowest average for this characteristic, amounting to 3.47 and 3.55 tons ha^{-1}, with a decrease rate of 38.36 and 39.10% for the two consecutive seasons. The reason for the decrease in grain yield with an increase in the depletion rate may be attributed to a decrease in one or more of the components of the yield, as the lack of water led to a reduction in the number of spike and also led to a reduction in the number of grains and grain weight, which had a negative impact on the yield.

The results of the table show that there was a significant increase in grain yield when treated with potassium spraying, which gave the highest average of 5.25 and 5.46 tons ha^{-1} for the two consecutive seasons, and without a significant difference with the spraying treatment with kaolin in the second season, compared to the comparison treatment (spraying water only), which gave the lowest The averages for this characteristic reached 3.64 and 3.79 tons ha^{-1}, with a decrease rate of 30.66 and 30.58% for the two consecutive seasons. The reason for the increase may be attributed to the role of potassium and kaolin in increasing one or more of the components of yield, including the number of spike and the number of grains per spike (**Table 1** and **Table 2**), which in turn was reflected in an increase in yield, in addition to the role of potassium and kaolin in alleviating the negative effects of water stress through their role in regulating fullness. Guard cells that result in the movement of water, partial closing of stomata, stimulating the process of assimilation of CO_2, and lowering the temperature of the plant, and then their role in facilitating the transfer of carbon assimilation products to the fertilized grains, which increased the grain yield[24–26]. This result is consistent with what was concluded by[12, 27–32].

It is noted from the interaction data that there is a significant response to the interaction of available water depletion, anti-transpiration, and potassium treatments in grain yield. The highest average grain yield was 6.16 tons ha^{-1}, which resulted from the combination S1 and potassium spraying for the first season. As for the second season, the same combination excelled without a significant difference with Combination S1 and kaolin spray. The positive interaction between levels of depletion, anti-transpiration agents, and potassium may be attributed to the stimulating role of anti-transpirants and potassium in withstanding water stress by reducing water loss through the transpiration process and improving the efficiency of water use by the plant .

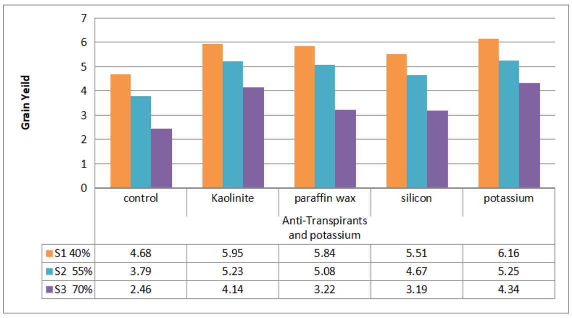

Figure 4. The effect of available water depletion levels, anti-transpiration agents, and potassium, and their interaction on grain yield (tons ha^{-1}) for the agricultural seasons 2022–2023.

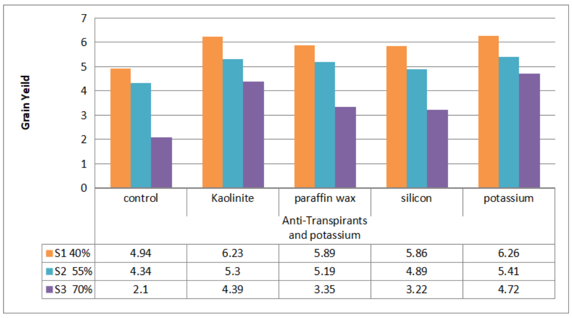

Figure 5. The effect of available water depletion levels, anti-transpiration agents, and potassium, and their interaction on grain yield (tons ha^{-1}) for the agricultural seasons 2023–2024.

5. Conclusions

The field experiment demonstrated that the application of anti-transpiration agents and potassium significantly improved grain yield and its components in wheat under water stress conditions. The treatment involving 40% depletion of available water showed the highest yield and water use efficiency, outperforming other depletion levels. Spraying with potassium and kaolin notably enhanced key yield traits, further optimizing water usage.

The S1 depletion treatment gave the highest averages for water use efficiency, amounting to 1.60 and 1.44 kg m^{-3} for the two consecutive seasons, compared to the S3 depletion treatment, which had the lowest averages for this characteristic, amounting to 1.14 and 1.02 kg m^{-3} for the two consecutive seasons These findings suggest that targeted use of these treatments can effectively mitigate the effects of water stress, improving wheat production and resource efficiency in water-limited environments.

Author Contributions

All authors contributed equally to all stages of the study, from conceptualization and study design to data collection, analysis, writing of the manuscript, and final approval of the published version.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Rysiak, A., Dresler, S., Hanaka, A., et al., 2021. High temperature alters secondary metabolites and photosynthetic efficiency in Heracleum sosnowskyi. International Journal of Molecular Sciences. 22(9), 4756.

[2] Hassan, D., Thamer, T., Mohammed, R., et al., 2023. Calibration and evaluation of AquaCrop model under different irrigation methods for maize (Zea mays L.) in central region of Iraq. In: Kallel, A., Barbieri, M., Rodrigo-Comino, J., et al. Selected studies in environmental geosciences and hydrogeosciences. CAJG 2020. Advances in Science, Technology & Innovation. Springer: Cham. DOI: https://doi.org/10.1007/978-3-031-43803-5_10

[3] El-Fattah, A., Hashem, F., Farag, A., 2021. Potentiality of using mycorrhizae and Pseudomonas fluorescens in reducing the effect of water shortage on broccoli plants. Arab Universities Journal of Agricultural Sciences. 29(3), 859–871.

[4] Muluneh, A., Stroosnijder, L., Keesstra, S., et al., 2017. Adapting to climate change for food security in the Rift Valley dry lands of Ethiopia: supplemental irrigation, plant density and sowing date. The Journal of Agricultural Science. 155(5), 703–724.

[5] Akol, A.M., Nassif, N., Jaddoa, K.A., et al., 2021. Effect of irrigation methods, tillage systems and seeding rate on water consumption, biological yield and harvest index of wheat (Triticum aestivum L.). International Journal of Agricultural & Statistical Sciences. 17.

[6] Abdelraouf, R.E., El-Shawadfy, M.A., Dewedar, O.M., et al., 2021. Field and modelling study for deficit irrigation strategy on roots volume and water productivity of wheat. Journal of Water and Land Development. 49 (IV–VI), 129–138.

[7] Zeydalinejad, N., Nassery, H.R., 2023. A review on the climate-induced depletion of Iran's aquifers. Stochastic Environmental Research and Risk Assessment. 37(2), 467–490.

[8] Daryanto, S., Wang, L., Jacinthe, P.A., 2016. Global synthesis of drought effects on maize and wheat production. PLOS ONE. 11(5), e0156362.

[9] Danish, S., Zafar-ul-Hye, M., 2019. Co-application of ACC-deaminase producing PGPR and timber-waste biochar improves pigments formation, growth and yield of wheat under drought stress. Scientific Reports. 9, 5999.

[10] Kettlewell, P.S., Heath, W.L., Haigh, I.M., 2010. Yield enhancement of droughted wheat by film antitranspirant application: rationale and evidence. Agricultural Sciences. 1, 143–147.

[11] Kocięcka, J., Liberacki, D., 2021. The potential of using chitosan on cereal crops in the face of climate change. Plants. 10(6), 1160.

[12] Abdallah, M.M.S., El-Bassiouny, H.M.S., AbouSeeda, M.A., 2019. Potential role of kaolin or potassium sulfate as anti-transpirant on improving physiological, biochemical aspects and yield of wheat plants under different watering regimes. Bulletin of the National Research Centre. 43, 1–12.

[13] Mphande, W., Kettlewell, P.S., Grove, I.G., et al., 2020. The potential of antitranspirants in drought management of arable crops: a review. Agricultural Water Management. 236, 106137.

[14] Morsy, A.S.M., Mehanna, H.M., 2022. Beneficial effects of antitranspirants on water stress tolerance in maize under different plant densities in newly reclaimed land. Bulletin of the National Research Centre. 46(1), 248.

[15] Del Amor, F.M., Cuadra-Crespo, P., Walker, D.J., et al., 2010. Effect of foliar application of antitranspirant on photosynthesis and water relations of pepper plants under different levels of CO_2 and water stress. Journal

of Plant Physiology. 167(15), 1232–1238.
[16] Zein, A.K., 2002. Rapid determination of soil moisture content by the microwave oven drying method. Sudan Engineering Society Journal. 48(40), 43–54.
[17] Hillel, D., 1980. Application of soil physics. Academic Press. Inc.: New York. pp. 116–126.
[18] Hasanuzzaman, M., Bhuyan, M.B., Nahar, K., et al., 2018. Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. Agronomy. 8(3), 31.
[19] Kovda, V.A., VandenBerg, C., Hangun, R.M., 1973. Drainage and salinity. FAO. UNE Co.: London.
[20] Allen, G., Pereira, S., Raes, D., et al., 1998. Crop evapotranspiration. FAO Irrigation and Drainage Paper. No. 56, 300 p. Rome, Italy.
[21] Al-Muaini, I.H.A., 2004. Response of bread wheat (Triticum aestivum L.) varieties for water stress and potassium fertilizer [PhD thesis]. College of Agriculture - University of Baghdad. p. 175.
[22] Amir, A., Qassem, O., 2018. The effect of anti-transpiration agents and humic acid on the growth, yield and quality of maize under conditions of water stress [PhD thesis]. College of Agricultural Engineering Sciences. Baghdad University.
[23] Mohammed, R.J., Hameed, I.A., Thamer, T.Y., 2022. Effect of using different types of well water in Karbala Governorate on soil and plant. Ecological Engineering & Environmental Technology. 23.
[24] Aown, M., Raza, S., Saleem, M.F., et al., 2012. Foliar application of potassium under water deficit conditions improved the growth and yield of wheat (Triticum aestivum L.). The Journal of Animal and Plant Sciences. 22(2), 431–437.
[25] AlJanaby, Z.A.A., Obeed, Z.O., Hamza, L.M., et al., 2020. The effect of compost NP and salicylic acid spray for quantity and quality of luxury variety grapes (Vitis vinifera L.). Plant Archives. 20(1), 2691–2694.
[26] Ali, Z.A., Hassan, D.F., Mohammed, R.J., 2021. Effect of irrigation level and nitrogen fertilizer on water consumption and faba bean growth. IOP Conference Series: Earth and Environmental Science. 722(1), 012043.
[27] Jaafer, A.A., Mohammed, R.J., Hassan, D.F., 2020. Studying the thermodynamic parameters for the evaluation of potassium availability by adding organic matter. Biochemical & Cellular Archives. 20(1).
[28] Jafaar, A.A., Mohammed, R.J., Hassan, D.F., 2022. Effect of phosphorus fertilizer and irrigation level on desert soil management and potato yield. International Journal of Agricultural & Statistical Sciences. 18(2).
[29] Jafaar, A.A., Mohammed, R.J., Hassan, D.F., et al., 2023. Effect of foliar seaweed and different irrigation levels on water consumption, growth and yield of wheat. IOP Conference Series: Earth and Environmental Science. 1252(1), 012057.
[30] Mohammed, R.J., Suliman, A.A., 2023. Land suitability assessment for wheat production using analytical hierarchy process and parametric method in Babylon Province. Journal of Ecological Engineering. 24(7).
[31] Elmasry, H.M., El-Rady, A., 2024. The effect of anti-transpirants on physiological aspects and yield of wheat crop under varied irrigation levels. Egyptian Journal of Soil Science. 64(1), 63–81.
[32] AlJanabi, A.Z., Ameer, A.J., Israa, H., et al., 2019. Effect of adding different levels of organic manure and potassium fertilizer in the yield growth of wheat (Triticum aestivum L.). Plant Archives. 19.