EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(10), 268–281
https://doi.org/10.12912/27197050/191985
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.07.23
Accepted: 2024.08.15
Published: 2024.09.01

Effects of Water Stress on Water Consumption, Water Use Efficiency of Different Wheat Varieties

Zaman Salah Al-Dulaimi[1*], Rafid S. Al Ubori[1], Shatha A.H. Ahmed[2]

[1] Department of Field Crops, Agriculture College, Al-Qasim Green University, Babylon, Iraq

[2] Department of Field Crops, College of Agriculture Engineering Science, University of Baghdad, Baghdad, Iraq

* Corresponding author's e-mail: zamansalah@agre.uoqasim.edu.iq

ABSTRACT

Given the challenges posed by climate change and population growth, Iraq faces increasing demands for food production and water resources. To enhance agricultural productivity and optimize water management for crop efficiency, this study evaluated various wheat varieties, specifically Mawaddah, Bohuth 10, Aba99, and Babel113, under different irrigation level. These level were based on depletion levels of available water at 40%, 55%, and 70%. Key metrics measured included actual evapotranspiration, water use efficiency (WUE), grain yield, spike number, grains per spike, and the weight of 100 grains over the growing seasons of 2022–2023 and 2023–2024. The findings revealed that water consumption varied with depletion levels for all wheat varieties, amounting to 435.53, 397.13, and 365.13 mm season^{-1}, and 465.7, 422.10, and 385.40 mm season^{-1} for the respective depletion levels of 40%, 55%, and 70%, across the two seasons. WUE ranged from 1.01 for Babel 113 at the 70% depletion level to 1.85 for Bohuth and Mawaddah at the 40% depletion level. Among the plant traits, Mawaddah had the best performance at the 40% depletion level, while Babel113 had the lowest performance at the 75% depletion level. The drought sensitivity index varied among the varieties due to their genetic differences. Our research supports the feasibility of utilizing water at depletion levels up to 75% when cultivating drought-tolerant wheat varieties in semi-arid and arid conditions.

Keywords: wheat, water stress, varieties, water use efficiency, drought sensitivity index.

INTRODUCTION

The wheat crop is considered at the top of the pyramid of major and critical crops for global food, despite the multiplicity of crops in quantity and quality, due to its strategic role in achieving food security in developing countries, as its grains constitute food almost 35% of the world's population. Climate changes, represented by the rise in atmospheric pollutants, especially CO_2, and the accompanying climate changes, including rising temperatures, decreased precipitation, and the risk of reduced water releases in Euphrates and Tigris rivers, as well as increased civil and industrial uses of water, expose plants to abiotic stresses, including water stress, especially in dry and semi-arid areas. Dry. Water is important because of its fundamental role in the field of agricultural and economic development in all parts of the world, including Iraq, which suffers from a major shortage due to climate change, declining rainfall, and the monopoly of water resources pursued by neighbouring countries. This situation has led to an increase in dry areas, so the trend in agricultural expansion requires effort in how to ration water and use it rationally. Bufon (2010) indicated that irrigation scheduling is one of the methods of irrigation management that aims to avoid excessive use of water, so the amount and need of the plant for water must be known in order to provide it.

One of the most cost-effective and easily implemented methods to address water shortages is the use of water-stress-tolerant plant varieties (Maleki, 2013). Varieties exhibit differing performances based on their growth stages; some are tolerant during the vegetative stage but sensitive during the reproductive stage, while others may be sensitive or tolerant in both stages. Their tolerance and sensitivity to water stress are evaluated through yield and its components (Reynolds et al., 2019), highlighting the importance of a variety's efficiency in water use to achieve the highest yield. This evaluation includes tests for water stress tolerance standards, such as the drought sensitivity index (Ali et al., 2021; Khan et al., 2022). AL-Fatlawi et al. (2023) studied the water stress response of seven wheat varieties under 3 irrigation levels like: 50% depletion (control), 65% depletion (medium stress), and 75% depletion (severe stress). They detected a decrease in biological yield with increasing water stress. Yield and its components were significantly lower under severe stress compared to the control, which had the highest averages for all traits. The decline in yield was attributed to water stress causing reduced plant growth indicators, including, flag leaf area, plant height as well as the number of branches. Water stress also led to decreased interception of solar rays, reduced change of solar energy into chemical energy due to stomatal closure, increased respiration, and biochemical disturbances, ultimately decreasing yield components and grain yield.

One major agricultural concern is increasing crop-water productivity to fulfil the increasing worldwide demand for food. (Sharma and Bhambota, 2022; Hassan et al., 2023). To optimize crop-water productivity, it is crucial to accurately and promptly identify crop water stress while minimizing water wastage in agricultural systems. Over time, several methods have been developed for monitoring crop water stress, including approaches based on soil water balance (both evapotranspiration and climate-based), soil moisture, and plant responses such as leaf/stem water potential, sap flow, and stomatal conductance (Sharma and Rai, 2022). Traditional irrigation scheduling based on soil water balance relies on monitoring estimated ETc (using the FAO two-step method) to maintain soil water balance and scheduling irrigation when soil moisture falls below a set threshold, determined by the crop's effective rooting depth and the soil's water holding capacity (King et al., 2021; Das et al., 2024). The scientific objectives of this study are as follows:

- testing various wheat varieties under different irrigation levels to determine which varieties are most tolerant to water stress and achieve high production under climate change,
- to improve the estimated wheat yield by considering the plant growth and yield,
- to evaluate the ETa, yield, and water use efficiency (WUE) of water stress under different water level.

MATERIALS AND METHODS

Experimental site

Two field experiments due 2022–2023 and 2023–2024 in the Saddat Al-Hindiyya district, Babylon Governorate, specifically in the Al-Mahanawiyah area within the extension farm experiment field affiliated with the Babylon extension training center, 8 km north of Babylon, located at latitude 32.61°N and longitude 44.30°E. A randomized complete block design (RCBD) with a split-plot arrangement and 3 replications was used for both experiments. Depletion – 40%, 55%, and 70% (S1, S2, and S3)—while the subplots included the varieties Mawaddah, Buhuth 10, Ibaa 99, and Babel 113.

The land was prepared and prepared according to the scientific recommendations followed: (1) the ploughing process was carried out using medium ploughing (Abdullah et al., 2014); (2) the land of the two experiments was fertilized with urea fertilizer (N 46%) at an amount of 200 kg N ha^{-1} added in three equal batches, the first when three complete leaves appeared (ZGs13) and the second at the elongation stage when the second node appears on the main stem (ZGs32) and the third batch at the beginning of the lining (ZGs40) according to the scale of Zadoks et al. (1974), and triple superphosphate fertilizer (P2O5 46%) was added at an amount of 100 kg ha^{-1} (P2O5) in one batch when preparing the soil after ploughing before smoothing (Jadoo and Saleh, 2013; Bishay, 2003), (3) weeds were controlled by manual weeding whenever necessary (Bishay, 2003), (4) irrigation was carried out based on depletion coefficients in the study; (5) the amount of seeds was according to the recommendations of the Ministry of Agriculture, ranging between 40–45 kg per acre; (6) the irrigation depth was according to the recommendations of the Food and Agriculture Organization of the United Nations (FAO); (7) the plants were harvested when they reached full maturity.

The land divided into three sectors, each with 12 experimental units. There were 1.5-meter separations between main treatments and replicates to prevent water leakage, and 0.75 meters between experimental units. Each experimental unit, measuring 4 m² (2 × 2 m), included 8 lines with 20 cm spacing and 2 meters in length. Seeds were planted on November 23rd and 26th for the first and second seasons, respectively, at a seed rate of 120 kg/ha, equating to 48 g per experimental unit, 6 g per line, with a seed depth of 5 cm.

Climate

Figures 1 and 2 illustrate how the region's climate, in particular elements like temperature, precipitation, evaporation, and wind, greatly affects both environmental balance and land deterioration. Generally speaking, the climate is characterized by a long, hot, dry summer that lasts from May to October. The average temperature is 11.94 °C in January, the lowest, and 37.41 °C in July, the highest. According to Mohammed and Suliman (2023), the minimum temperature recorded the lowest average of 1.29 °C during the period of 2011–2021, while the maximum temperature recorded the greatest average of 48.72 °C in August and the lowest average of 23.4 °C in January.

The rainy season begins in October and continues until the end of May. The highest rainfall is in February, reaching 155 mm. The lowest rainfall is 12 mm in April and stops completely between June, July, and August. Evaporation rates also increase in hot seasons. The highest rate of evaporation is in July, reaching 8.52 mm.day^{-1}, and the lowest rate is in January, reaching 1.22 mm·day^{-1}.

Physical and chemical characteristics

The soil characteristics of the experimental field soil were assessed by collecting undisturbed soil samples from various locations at a depth of 0–30 cm before planting. First, the top 5 cm of the soil surface was scraped away. The collected samples were thoroughly mixed to ensure homogeneity, then air-dried and smoothed for analysis. Additionally, an irrigation water sample was taken from the river for similar analysis, as detailed in Table 1.

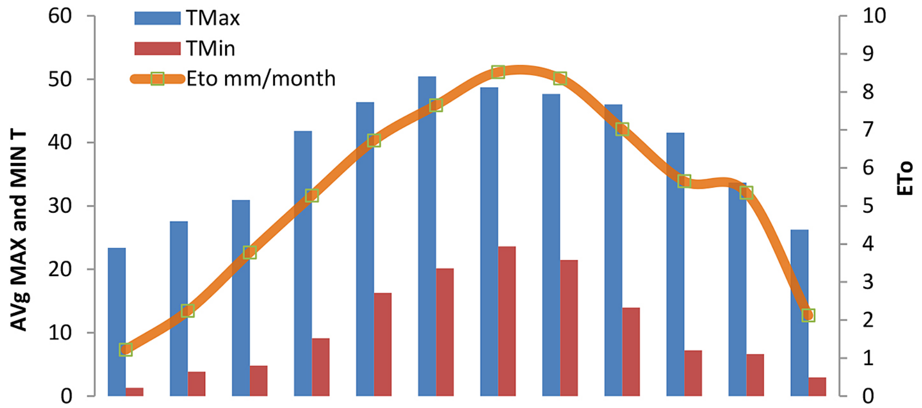


Figure 1. Climate data max, min tempruture and ETo

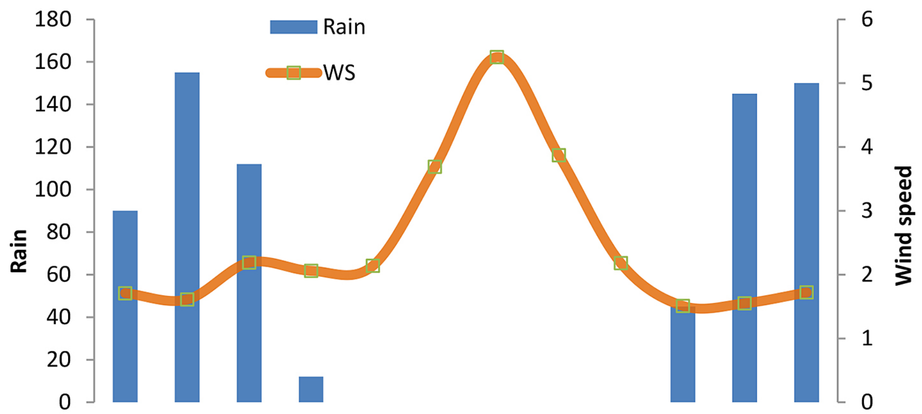


Figure 2. Climate data rain and wind speed

Table 1. Physical and chemical characteristics of field soil before planting

<table>
<tr><th>No.</th><th>Characteristics</th><th colspan="2">Value</th><th>Unit</th></tr>
<tr><td rowspan="3">1</td><td colspan="4">Ph</td></tr>
<tr><td>Soil</td><td colspan="2">7.9</td><td>-</td></tr>
<tr><td>Water</td><td colspan="2">7.7</td><td>-</td></tr>
<tr><td rowspan="3">2</td><td colspan="4">Ec</td></tr>
<tr><td>Soil</td><td colspan="2">3</td><td rowspan="2">Ds·M^{-1}</td></tr>
<tr><td>Water</td><td colspan="2">2.1</td></tr>
<tr><td>3</td><td>O.m</td><td colspan="2">0.57</td><td>Gm·kg^{-1}</td></tr>
<tr><td>4</td><td>Porosity</td><td colspan="2">42</td><td>%</td></tr>
<tr><td>5</td><td>Bulk density</td><td colspan="2">1.39</td><td>M gm·m^{-3}</td></tr>
<tr><td rowspan="3">6</td><td colspan="4">Available K</td></tr>
<tr><td>Soil</td><td colspan="2">160</td><td>Ppm</td></tr>
<tr><td>Water</td><td colspan="2">8.3</td><td>Ppm</td></tr>
<tr><td rowspan="3">7</td><td colspan="4">Available P</td></tr>
<tr><td>Soil</td><td colspan="2">7.2</td><td>Ppm</td></tr>
<tr><td>Water</td><td colspan="2">6.3</td><td>Ppm</td></tr>
<tr><td rowspan="3">8</td><td colspan="4">Available N</td></tr>
<tr><td>Soil</td><td colspan="2">43.5</td><td>Ppm</td></tr>
<tr><td>Water</td><td colspan="2">15.5</td><td>Ppm</td></tr>
<tr><td rowspan="3">9</td><td rowspan="3">Soil particles</td><td>Sand</td><td>5.16</td><td rowspan="3">Gm·kg^{-1}</td></tr>
<tr><td>Silt</td><td>60.84</td></tr>
<tr><td>Clay</td><td>34</td></tr>
<tr><td>10</td><td>Soil texture</td><td colspan="3">Silty clay loam</td></tr>
<tr><td>11</td><td>Water content at f.c</td><td colspan="2">0.428</td><td>Cm^{-3} cm^{-3}</td></tr>
<tr><td>12</td><td>Water content at pwp</td><td colspan="2">0.23</td><td>Cm^{-3} cm^{-3}</td></tr>
<tr><td>13</td><td>Available water</td><td colspan="2">0.198</td><td>Cm^{-3} cm^{-3}</td></tr>
</table>

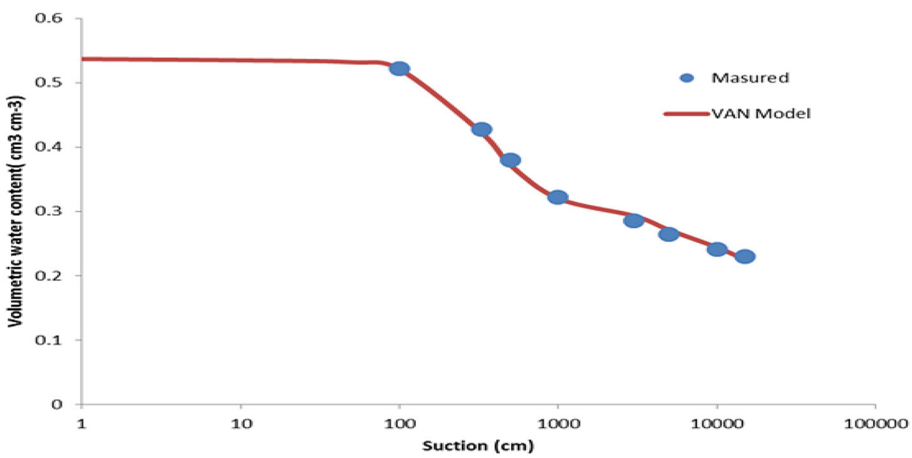


Figure 3. Water content curve retention for the soil study

Soil moisture content

The gravimetric method was employed to determine the soil's moisture content by collecting soil samples with an auger one day prior to irrigation. Samples were taken from two depths: 20 cm from planting to the branching stage and 30 cm from the branching stage to physiological maturity. These samples were placed in pre-weighed aluminum cans and then weighed while wet. Subsequently, they were dried in a microwave oven at 105 °C for 12 minutes, with the temperature and drying time attuned according to Zein's (2002) method using an electric oven. After drying Hillel (1980).

$$pw = \frac{mw - dw}{dw} \times 100 \quad (1)$$

where: pw – moisture content based on dry weight; mw – wet weight (g); dw – dry weight (g).

Irrigation and water volume calculation

Irrigation was finished utilizing plastic cylinders associated with a fixed-release electric siphon, and a meter was connected to the cylinder to gauge the water going through the tube in liters. Equivalent measures of water were added to all boards at planting (first irrigation) and inside the restrictions of field ability to guarantee 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 (Kovda et al., 1973).

$$d = (\Theta fc - \Theta w) \times D \quad (2)$$

where: 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).

The amounts of water were equivalent to 63, 87, and 111 litres/4 m^2 at a depth of 20 cm for the first three irrigations and 95, 130, and 166 litres/4 m2 at a plant depth of 30 cm for the remaining irrigations and the three treatments in succession.

Grain yield and its components

Number of grains per spike (spikes^{-1})

The average number of grains per spike was calculated for a random sample of ten spikes for each experimental unit.

Weight of 1000 tablets (g)

1000 grains were occupied randomly from the grain yield of every experimental unit (Briggs and Aytenfius, 1980), weighed, and returned to the yield.

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

The number of spikes was calculated from an area of 1 m^2 of the harvested area.

Grain yield

Grains were separated from the harvested sample plants for an area of 1 m^2 from each experimental unit and then converted to tons ha^{-1}. For calculating the actual water consumption of the wheat crop (Robertson et al., 1994).

$$ETa = I + C \quad (3)$$

where: WUE – water use efficiency was measured according to the following equation (AOAC):

$$WUEf = \frac{Y}{WA} \quad (4)$$

where: WUE_f – efficient use of field water (kg m^{-3}); Y – grain yield (kg); and WA – amount of water added in the irrigation process (m^3 $season^{-1}$).

The sensitivity index to water tension was calculated using the Equation given by Fisher and Maurer (1978).

$$S = \left(1 - \frac{Ys}{Yp}\right) \Big/ \left(1 - \frac{\bar{Y}s}{\bar{Y}p}\right) \quad (5)$$

where: S – index of sensitivity to tension; Ys – grain yield of the variety under tension; Yp – grain yield of the same variety under normal conditions (without tensioning), $\bar{Y}s$ – average grain yield of varieties under tension, $\bar{Y}p$ – average grain yield of varieties under normal conditions (without tensioning).

RESULTS AND DISCUSSION

Actual water consumption

Table 2 and Figure 4 illustrate the variation in actual water consumption rates (ETa) based on irrigation treatment depletion levels. The irrigation treatment with 40% depletion of available water (S1) recorded the highest water consumption rates, with 405.35 and 465.7 mm per season for the two consecutive seasons, averaging 435.53 mm per season. This was followed by the 55% depletion treatment (S2), with 372.15 and 422.1 mm per season, averaging 397.13 mm per season. The 70% depletion treatment (S3) had the lowest water consumption rates, with 344.85 and 385.40 mm per season, averaging 365.13 mm per season.

The table indicates that water consumption in the depletion treatments S1 and S2

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

Season	Depletion	No Irrigation	Water depth mm	Rain Depth mm	Eta per season
2022–2023	S1	12	300	105.35	405.35
	S2	10	266.8	105.35	372.15
	S3	8	239.5	105.35	344.85
2023–2024	S1	13	406.2	59.5	465.7
	S2	11	362.6	59.5	422.1
	S3	9	325.9	59.5	385.4

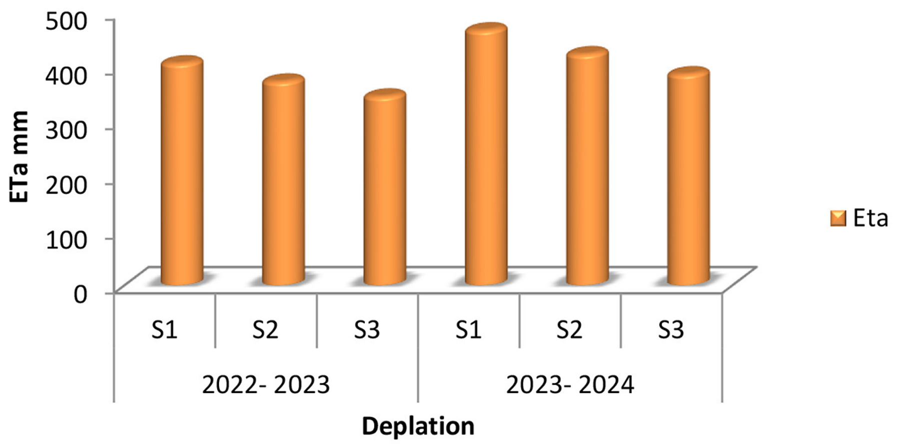


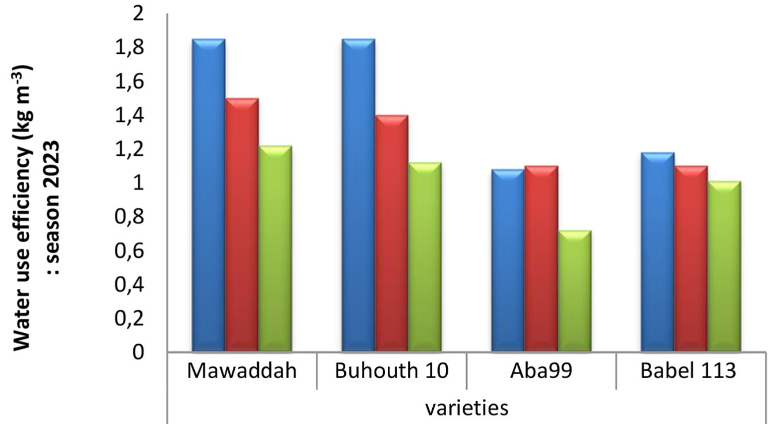
Figure 4. Actual water consumption (mm) for each depletion treatment in the seasons 2022–2023 and 2023–2024

was the highest, whereas treatment S3 had the lowest water consumption. The humidity levels in treatments S1 and S2 were close to the field capacity value, leading to increased water loss through evaporation and transpiration. This is expected, as higher humidity positively impacts plant canopy development, thereby increasing the amount of water lost through these processes (Jaffar et al., 2023).

Water use efficiency (kg m^{-3})

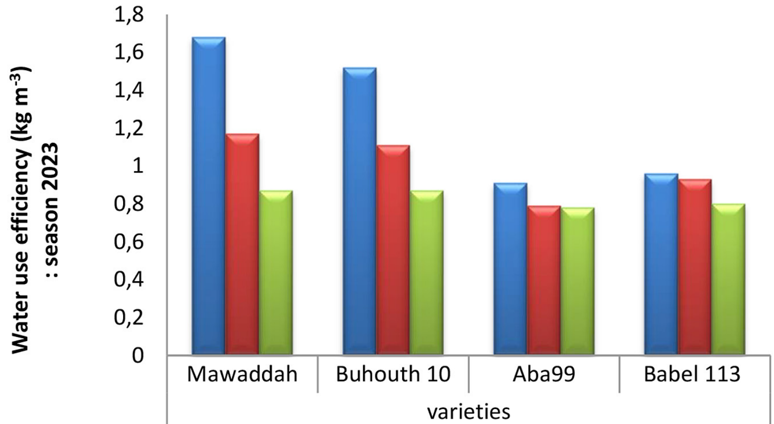
Figures 5 and 6 show substantial differences in WUE for grain yield across the two seasons, influenced by the depletion of available water, the varieties, and their interactions. The treatment with 40% water depletion (S1) yielded the highest average WUE, reaching 1.49 and 1.27 kg m^{-3} for the 2 seasons, respectively. Conversely, the 70% water depletion treatment (S3) resulted in the lowest averages, with 1.02 kg m^{-3} in the first season and 0.83 kg m^{-3} in the second season. This was not significantly different from the S2 treatment, which had a value of 1.00 kg m^{-3}. The S1 treatment increased water use efficiency by 46.07% and 53.01% over the S3 treatment in the respective growing seasons. The decrease in water use efficiency with higher depletion levels may be attributed to the direct relationship between water consumption and yield, as well as the reduction in grains per spike, spike number, and grain weight (Figure 8–14), leading to a significant (Table 2). This finding aligns with Shrief and El-Mohsen (2015) and Raza et al. (2023), who demonstrated that higher depletion levels reduce water use efficiency.

Additionally, the outcomes showed an important impact of the varieties on water use efficiency. The Mawaddah variety significantly outperformed the Bohuth 10 variety in both seasons, with averages of 1.52 and 1.46 kg m^{-3} in the first season and 1.24 and 1.17 kg m^{-3} in the 2nd season, respectively. The Aba 99 variety noted the lowest averages, 0.97 and 0.82 kg m^{-3}, for the two seasons, respectively, with no significant difference from the Babel 113 variety, which averaged 0.90 kg m^{-3} in the 2nd season. The superior water use efficiency of Mawaddah and Bohuth 10 may be due to their higher yield components, positively impacting yield and efficiency. These results are consistent with Farkas et al. (2020) and Bakry et al. (2019), who noted that WUE in wheat varieties is influenced by water stress levels.



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	1,85	1,85	1,08	1,18
S2 Deplation 55%	1,5	1,4	1,1	1,1
S3 Deplation 70%	1,22	1,12	0,72	1,01

Figure 5. Effect of available water depletion levels, varieties, and the interaction between them on the WUE (kg m^{-3}) for the 2022 season



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	1,68	1,52	0,91	0,96
S2 Deplation 55%	1,17	1,11	0,79	0,93
S3 Deplation 70%	0,87	0,87	0,78	0,8

Figure 6. Effect of available water depletion levels, varieties, and the relations between them on the WUE (kg m^{-3}) for the 2023 season

The table also showed a significant interaction effect between depletion levels, varieties, and growing seasons on this trait. The combination of Mawaddah and Bohuth 10 varieties consistently gave the highest averages for this trait across all depletion levels, while the Baba99 variety had the lowest averages.

Drought sensitivity index

Figure 7 shows that there was an important difference in the index for drought sensitivity in the second season only, although there was no significant effect on the evidence of the index for drought sensitivity in the first season. The Babel 113 variety showed the lowest average for the trait, amounting to 0.56 and 0.60, respectively, and it is different from the Abaa 99 variety in the season. Second, the results indicated that the sensitivity of the Mawaddah and Buhouth 10 cultivars to water stress reached 1.23 and 1.17 for the two cultivars, respectively, for the 2nd season. The reason for the variation of varieties in their sensitivity to water stress may be due to genetic differences among them in the mechanism of

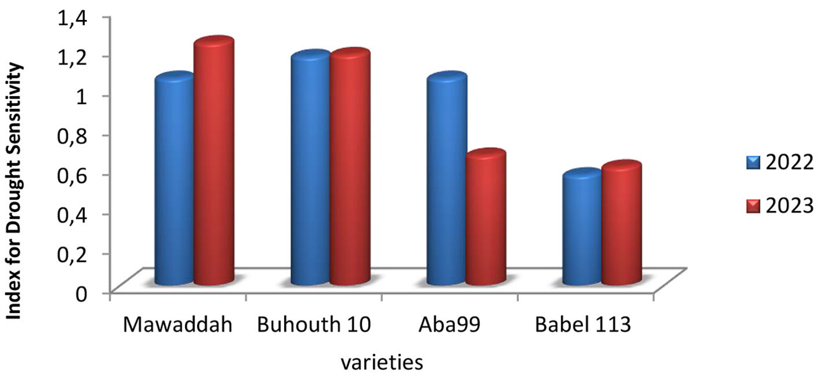
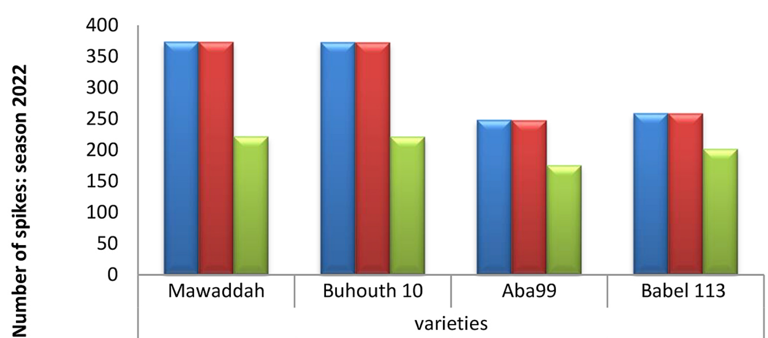


Figure 7. Effect of varieties on index for drought sensitivity for the 2023 season

their resistance to that stress and their ability to reduce the loss that occurs to the yield and its components when exposed to water stress (Rana et al., 2017). The sensitivity of varieties to water stress also depends on the nature of their growth. Varieties that have a short growing season and are early in flowering and maturation will have little effect on them. They are characterized by relative stability in yield, such as the Babel 113 variety. For two successive planting seasons, they carry the lowest values for drought sensitivity, unlike late-flowering and maturing varieties, whose yield is affected by It was exposed to reduced water deficiency during the flowering and grain-filling stages, especially when these stages coincide with high temperatures, wind speed, and low humidity (Appendices 1 and 2), as in research varieties 10 and Mawaddah for the two growing seasons, which increased the evidence of its sensitivity to water stress. This result is consistent with what was concluded by Khan. et al (2022) and Chaouachi et al (2023).

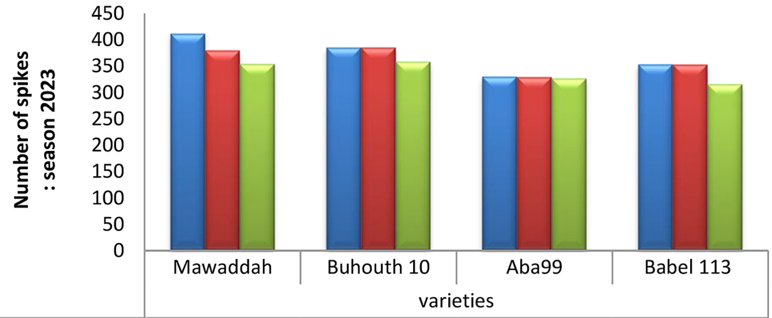
Number of spikes (m^{-2})

Water depletion and variations in the number of spikes for the two research seasons are depicted in Figures 8 and 9, with only the first season showing a significant interaction. The highest average number of spikes was produced by the irrigation treatment with 40% of the available water drained (S1), reaching 313.42 and 370.08 spikes m^{-2} for the two consecutive seasons, respectively. Comparing this to the irrigation treatment with 55% depletion, there was no discernible difference (S2). By comparison, the treatment with 70% depletion (S3) resulted in the least average amount of spikes over the course of two seasons (205.0 and 338.58 spikes m^{-2}). Since the stage of stripping is nearing, the decrease in the number of shoots that subsequently spike may be the cause of the spike number decline with increased depletion.is particularly sensitive to water stress, depending on the duration and intensity of the stress. This effect is more pronounced at the start of vegetative growth, leading to fewer fertile



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	373,67	372,67	248,33	259
S2 Deplation 55%	373,33	372,33	247,67	258,67
S3 Deplation 70%	221,67	221,33	175,33	201,67

Figure 8. Effect of water depletion levels, varieties, and the interaction between them on the number of spikes (spikes m^{-2}) for the season 2022



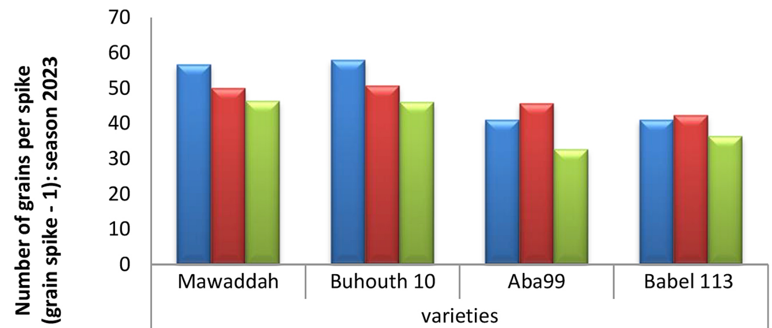
	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	411,67	385,33	330	353,33
S2 Deplation 55%	379,67	385	329	352,67
S3 Deplation 70%	354	358,33	326,33	315,67

Figure 9. Effect of water depletion levels, varieties, and the interaction between them on the Number of spikes (spikes m^{-2}) for the season 2023

branches and spikes (Liwani, 2017). These findings align with those of Liwani et al. (2019) and Kreet and Al Hasson (2020), who also found that water stress significantly reduces the number of fertile spikes. The results also show that the Mawaddah variety, 322.89 and 381.78 spikes m^{-2} for the two seasons, respectively, are not significantly different from the Bohouth 10 variety. In contrast, the Ibaa 99 variety had the lowest averages, with 223.78 and 328.44 spikes m^{-2}, showing no significant difference from the Babel 113 variety in the second season. The variation in spike numbers among the varieties could be due to differences in the number of shoots forming spikes and their ability to allocate nutrients to productive shoots. The combination of the S1 treatment and the Mawaddah variety resulted in the highest average number of spikes, with 373.67 spikes m^{-2}, not significantly different from combinations of S2 and Mawaddah, S1 and Bohouth 10, and S2 and Bohouth 10. Conversely, the lowest average, 175.33 spikes m^{-2}, was observed for the combination of the S3 treatment and the Ibaa 99 variety.

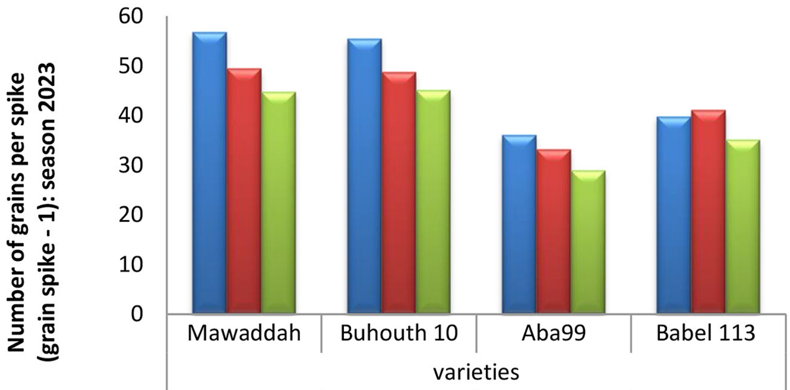
Number of grains per spike (spike^{-1})

Figures 10 and 11 show that the 40% water depletion treatment (S1) yielded the highest number of grains per spike, averaging 49.17 and 47.00 grains per spike over two consecutive seasons. In contrast, the 70% depletion treatment (S3) recorded the lowest averages, with 40.33 and 38.46 grains per spike, reflecting decreases of 18.6% and 18.17% compared to the S1 treatment. The decline in grain number is attributed to increased depletion rates, leading to reduced dry matter accumulation and carbon metabolism products due to water stress. This stress heightens competition between the rapidly elongating



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	56,67	58	41	41
S2 Deplation 55%	50	50,67	45,67	42,33
S3 Deplation 70%	46,33	46	32,67	36,33

Figure 10. Effect of available water depletion levels, varieties, and the interaction between them on the number of grains per spike (grain spike $^{-1}$) seasons 2022



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	56,75	55,42	36,08	39,75
S2 Deplation 55%	49,42	48,75	33,13	41,08
S3 Deplation 70%	44,75	45,08	28,93	35,08

Figure 11. Effect of available water depletion levels, varieties, and the interaction between them on the number of grains per spike (grain spike $^{-1}$) seasons 2023

stem and the spikelet primordia, resulting in fewer grains. Additionally, stress during late developmental stages, such as node elongation and the early floret stage, likely causes floret abortion. These findings align with those of Isidro et al. (2011) and Farooq et al. (2014), who linked reduced grain numbers to irrigation water availability before and during flowering.

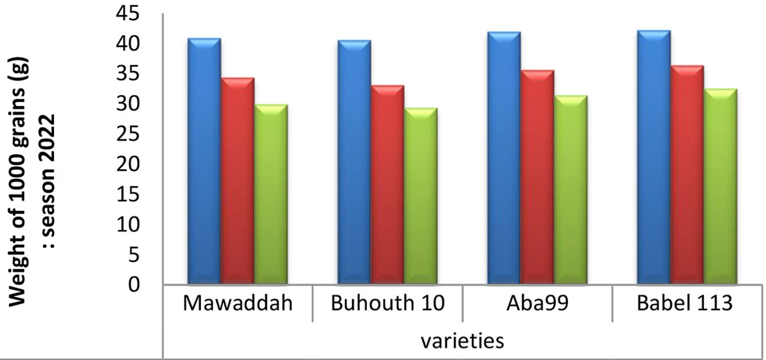
The varieties also showed significant differences in grain numbers per spike. In the first season, the Bohuth 10 variety outperformed the Mawaddah variety, averaging 51.56 and 51.00 grains per spike, respectively. In the second season, Mawaddah significantly surpassed Bohuth 10, with Bohuth 10 averaging 50.31 and 49.75 grains per spike. The Abaa 99 variety had the lowest averages, with 39.78 and 32.72 grains per spike over two seasons, showing no significant difference from the Babel 113 variety in the first season. The variation in grain numbers among varieties can be attributed to genetic traits and environmental factors, including the varieties' growth characteristics under water stress and their ability to form florets that develop into grains due to the nutritional supply under these conditions. These results are consistent with findings by Isidro et al. (2011) and Hou et al. (2018), who reported that grain numbers per spike are positively related to environmental and genetic factors.

The interaction between water depletion treatments and varieties significantly affected grain numbers per spike in the first season only. The combination of Bohuth 10 with the 40% (S1) yielded highest grain number average per spike, not significantly different from the Mawaddah variety with the same treatment. Conversely, the combination of Abaa 99 with the 70% depletion treatment (S3) recorded the lowest average, with 32.67 grains per spike, showing no significant difference from the Babel 113 variety under the same treatment.

Weight of 1000 grains (g)

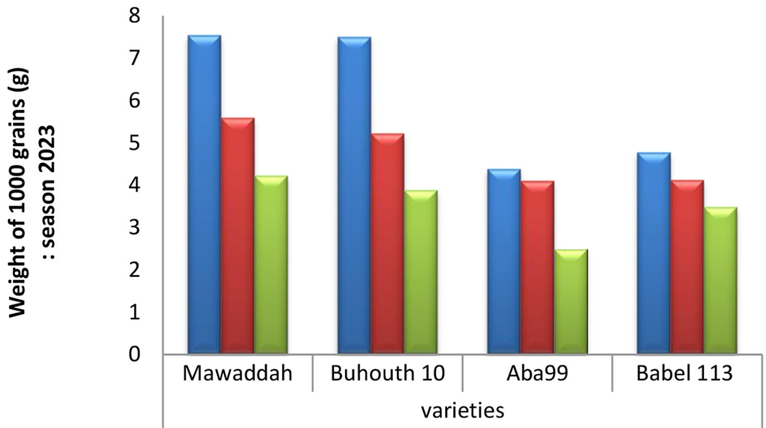
Figures 12 and 13 indicate significant differences in the weight of 1000 grains across the depletion treatments and varieties, with no significant interaction effect over the two seasons.

The results show that 40% (S1) produced the highest 1000-grain weight, averaging 41.36 and 42.49 grams for the two seasons, respectively. In contrast, the 70% depletion treatment (S3) had the lowest averages, at 30.74 and 30.40 grams for the two consecutive seasons. This reduction in grain weight under water stress is likely due to decreased vegetative characteristics, such as the flag leaf area, which is crucial for metabolite preparation during grain filling. This reduction leads to smaller and fewer grains and less accumulated dry matter transferred to the grains. These findings align with those of Devesh et al. (2019) and Siyal et al. (2020), who demonstrated that final grain weight depends on the source strength and downstream capacity. When source efficiency declines, downstream transport also decreases, influenced by the quantity and duration of nutrient preparation from flowering to physiological maturity.



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	40,87	40,5	41,93	42,15
S2 Deplation 55%	34,3	33,03	35,57	36,33
S3 Deplation 70%	29,87	29,27	31,37	32,47

Figure 12. Effect of available water depletion levels, varieties, and the interaction between them on the weight of 1000 grains (g) for the 2022 season



	Mawaddah	Buhouth 10	Aba99	Babel 113
S1 Deplation 40%	7,54	7,5	4,38	4,77
S2 Deplation 55%	5,59	5,22	4,1	4,12
S3 Deplation 70%	4,22	3,88	2,49	3,48

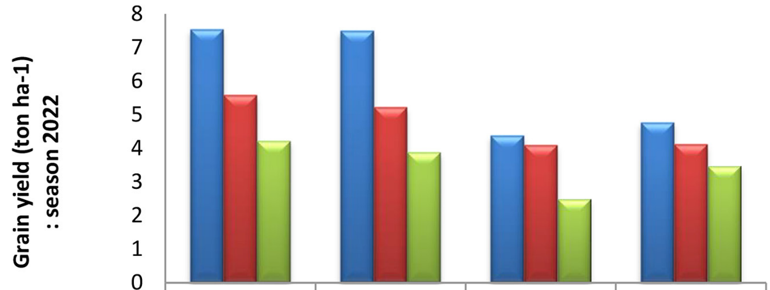
Figure 13. Effect of available water depletion levels, varieties, and the interaction between them on the weight of 1000 grains (g) for the 2023 season

The Babel 113 variety showed significant superiority in 1000-grain weight, averaging 36.98 and 37.67 grams for the two seasons, without a significant difference from the Abaa 99 variety in the first season. The Buhouth 10 variety had the lowest averages, with 34.27 and 35.09 grams over the two seasons, and no significant difference from the Mawaddah variety. Variations in 1000-grain weight among varieties may be attributed to genetic differences in grain filling duration or grain number per spike. Fewer grains per spike result in heavier grains due to the compensation principle, where fewer grain sites lead to less competition for nutrients (Jadoua et al., 2017).

Grain yield (ton ha^{-1})

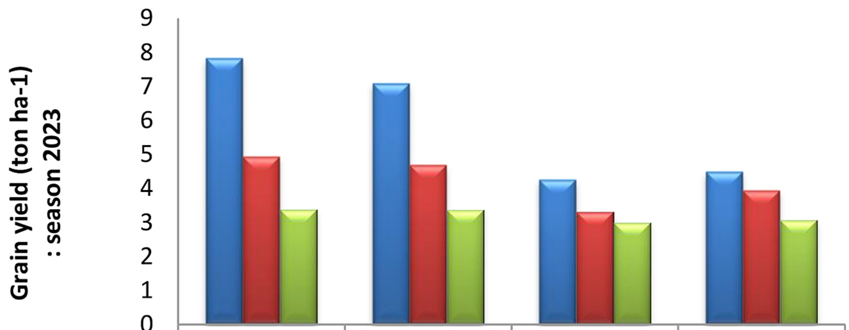
Figures 14 and 15 show significant effect of water stress, varieties, and their interaction on grain yield characteristics over two seasons.

The 40% (S1) highest grain yields, averaging 6.05 and 5.92 tons ha^{-1} for the two consecutive seasons. In contrast, the 70% depletion treatment (S3) resulted in the lowest yields, with 3.52 and 3.21 tons ha^{-1}, reflecting decreases of 41.81% and 45.77% compared to S1. The reduction in grain yield with increased depletion is likely due to declines in key yield components, such as the number of spikes, grains per spike, and grain weight, as well as the adverse effects of water shortage



	Mawaddah	Buhouth 10	Aba99	Babel 113
	varieties			
S1 Deplation 40%	7,54	7,5	4,38	4,77
S2 Deplation 55%	5,59	5,22	4,1	4,12
S3 Deplation 70%	4,22	3,88	2,49	3,48

Figure 14. Effect of available water depletion levels, varieties, and the interaction between them on the grain yield (ton ha^{-1}) for the 2022 season



	Mawaddah	Buhouth 10	Aba99	Babel 113
	varieties			
S1 Deplation 40%	7,83	7,09	4,26	4,49
S2 Deplation 55%	4,93	4,69	3,32	3,94
S3 Deplation 70%	3,38	3,37	3	3,07

Figure 15. Effect of available water depletion levels, varieties, and the interaction between them on the grain yield (ton ha^{-1}) for the 2023 season

combined with high temperatures during the grain filling period. These factors shorten the filling period and reduce the amount of accumulated dry matter transferred to the grain, negatively impacting yield. These findings are consistent with those of Hafez and Seleiman (2017) and Bandgar et al. (2020), who reported that water stress leads to decreased grain yield. Varieties also showed significant differences in grain yield. The Mawaddah variety outperformed Bohouth 10 in both growing seasons, with yields of 5.78 and 5.54 tons ha^{-1} for the first season and 5.38 and 5.05 tons ha^{-1} for the second season, respectively. Mawaddah achieved the highest yield increases, at 57.92% and 52.41% for both seasons, compared to the Abaa 99 variety, which had the lowest averages of 3.66 and 3.53 tons ha^{-1}. Abaa 99 did not differ significantly from Babel 113, which recorded 3.83 tons ha^{-1} in the second season. The higher grain yields of Mawaddah and Bohouth 10 may be attributed to their superior number of spikes per unit area and grains per spike, key components closely related to yield. These results align with findings by Abd El-Rady and Koubisy (2023), and AL-Fatlawi et al. (2023), who showed that yield increases result from improvements in one or more of its components. Additionally, the interaction between depletion levels and varieties significantly affected yield in both seasons, with the combination of Mawaddah and Bohouth 10 varieties producing the highest averages across all depletion treatments.

CONCLUSIONS

In this study, In order to calculate wheat yield, we took into account plant growth and yield as well as the ETa, yield, and WUE of water stress at various water levels. Wheat yield and ETa increased with irrigation, and certain wheat types' induced yield increases were well-suited to withstand water stress. Wheat plants grown under the treatment of depletion of 40% of the available water excelled in grain yield as a result of their superiority in the number of grains per spike, number of spikes, as well as the weight of 1000 grains. Compared to the 70% depletion treatment, which achieved the lowest average grain yield. The 40% depletion treatment also noted the highest WUE. Our research fills a essential gap in understanding the various responses of wheat varieties to water stress, providing valuable insights for breeding programs aimed at developing drought-resistant crops. The findings also open new prospects for improving wheat resilience to climate change, emphasizing the importance of selecting and cultivating varieties with superior WUE to sustainable agricultural productivity in water-limited environments.

REFERENCES

1. Al-Fatlawi, Z.H., Farhood, A.N., Mahdi, S.A.A., and Al-Tmime, A.H.T. 2023. Evaluation of seven different wheat cultivars for their resistance to drought in terms of growth indicators and yield. J. Appl. Biol. Biotechnol, 11(1), 188–194.
2. Bakry, A.B., Sh, S.M., El-Karamany, M.F., Tawfik, M.M. 2019. Sustainable production of two wheat cultivars under water stress conditions. Plant Archives, 19(2), 2307–2315.
3. Hillel, D. 1980. Application of Soil Physics. Academic press. Inc. New York.116–126.
4. Abdullah, A.S. 2014. Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of Northern Iraq. Soil and Tillage Research, 144, 150–155.
5. Al-Asadi, Salman, M.H. 2019. GenStat. To analyze agricultural experiments. Al-Qasim Green University - College of Agriculture. Dar Al-Warith Printing and Publishing Press. Iraq. 304.
6. Ali, Z.A., Hassan, D.F., Mohammed, R.J. 2021, April. Effect of irrigation level and nitrogen fertilizer on water consumption and faba bean growth. In IOP Conference Series: Earth and Environmental Science 722(1), 012043. IOP Publishing.
7. Allen, G.R., Pereira, S.L., Raes, D., Smith, M. 1998. Crop Evapotranspiration. FAO Irrigation and Drainage, 56, 300.
8. Al-Rawi, K.M. and Allah A.A.M.K. 2000. Design and analysis of agricultural experiments. Dar Al-Kutub Printing and Publishing Foundation. University of Al Mosul. Iraq. 488.
9. Bandgar, A., Bharad, S.G., Potdukhe, N.R., Tayade, S.D., Amarshettiwar, S.B. 2020. Effect of moisture stress on morpho-physiological traits of wheat (*Triticum aestivum* L.) genotypes. Journal of Pharmacognosy and Phytochemistry, 9(1), 361–364.
10. Bishay, F.K. 2003. Towards sustainable agricultural development in Iraq. The transition from relief, rehabilitation and reconstruction to development.
11. Briggs, K., and Aytenfisu, A. 1980. Relationships between morphological characters above the flag leaf node and grain yield in spring wheat 1. Crop Science, 20(3), 350–354.
12. Bufon, V.B. 2010. Optimizing subsurface drip irrigation design and management with hydrus-2D/3D model. Texas Tech University, Vinicius Bof Bufon.
13. Chaouachi, L., Marín-Sanz, M., Kthiri, Z., Boukef, S., Harbaoui, K., Barro, F., and Karmous, C. 2023. The opportunity of using durum wheat landraces to tolerate drought stress: screening morpho-physiological components. AoB Plants, 15(3), plad022.
14. Das, S., Kaur, S., Sharma, V. 2024. Determination of threshold crop water stress index for sub-surface drip irrigated maize-wheat cropping sequence in semi-arid region of Punjab. Agricultural Water Management, 301, 108957.
15. Devesh, P., Moitra, P.K., Shukla, R.S., and Pandey, S. 2019. Genetic diversity and principal component analyses for yield, yield components and quality traits of advanced lines of wheat. Journal of Pharmacognosy and Phytochemistry, 8(3), 4834–4839.
16. Ehdaie, B., and Waines, J.G. 1993. Variation in water-use efficiency and its components in wheat: I. Well-watered pot experiment. Crop Science, 33(2), 294–299.
17. El-Rady, A., Ayman, G., and Koubisy, Y. 2023. Evaluation of some bread wheat genotypes for grain yield and components under water stress conditions. Egyptian Journal of Agricultural Research, 101(1), 110–118.
18. Farkas, Z., Varga-László, E., Anda, A., Veisz, O., and Varga, B. 2020. Effects of waterlogging, drought and their combination on yield and water-use efficiency of five Hungarian winter wheat varieties. Water, 12(5), 1318.
19. Farooq, M., Hussain, M., and Siddique, K.H. 2014. Drought stress in wheat during flowering and grain-filling periods. Critical Reviews in Plant Sciences, 33(4), 331–349.
20. Fischer, R.A., and Maurer, R. 1978. Drought

resistance in spring wheat cultivars. I. Grain yield responses. Australian Journal of Agricultural Research, 29(5), 897–912.

21. Hafez, E.M., and Seleiman, M.F. 2017. Response of barley quality traits, yield and antioxidant enzymes to water-stress and chemical inducers. International Journal of Plant Production, 11(4), 477–490.
22. Hassan, D., Thamer, T., Mohammed, R., Almaeini, A., Nassif, N. 2023. Calibration and evaluation of aquacrop model under different irrigation methods for maize (*Zea mays* L.) in central region of Iraq. In: Kallel, A., et al. Selected Studies in Environmental Geosciences and Hydrogeosciences. CAJG 2020. Advances in Science, Technology & Innovation. Springer, Cham. https://doi.org/10.1007/978-3-031-43803-5_10
23. Hou, J., Huang, X., Sun, W., Du, C., Wang, C., Xie, Y., and Ma, D. 2018. Accumulation of water-soluble carbohydrates and gene expression in wheat stems correlates with drought resistance. Journal of Plant Physiology, 231, 182–191.
24. https://www.fao.org/land-water/databases-and-software/crop-information/wheat/en/
25. Isidro, J., Alvaro, F., Royo, C., Villegas, D., Miralles, D.J., and García del Moral, L.F. 2011. Changes in duration of developmental phases of durum wheat caused by breeding in Spain and Italy during the 20th century and its impact on yield. Annals of Botany, 107(8), 1355–1366.
26. Jadoua, K.A. and Saleh H.M. 2013. Fertilizing wheat crops. Guidance Bulletin No. (2) Ministry of Agriculture. The National Program for the Development of Wheat Agriculture in Iraq. 12.
27. Jafaar, A.A., Mohammed, R.J., Hassan, D.F., Thamer, T.Y. 2023, December. Effect of Foliar Seaweed and Different Irrigation Levels on Water Consumption, Growth and Yield of Wheat. In IOP Conference Series: Earth and Environmental Science 1252(1), 012057. IOP Publishing.
28. Khan, F.Y., Khan, S.U., Gurmani, A.R., Khan, A., Ahmed, S., and Zeb, B.S. 2022. Effect of water stress through skipped irrigation on growth and yield of wheat. Polish Journal of Environmental Studies, 31(1), 713–721.
29. King, B.A., Tarkalson, D.D., Sharma, V., Bjorneberg, D.L. 2021. Thermal crop water stress index base line temperatures for sugarbeet in arid western US. Agricultural Water Management, 243, 106459.
30. Kovda, V.A., VandenBerg C. and Hangun R.M. 1973. Drainage and salinity. FAO. UNE Co. London.
31. Kreet, A.M., and Al Hasson, S.N. 2020. Effect of water and salt stress on growth and yield of two varieties of wheat (*Triticum aestivum* L.). Plant Archives, 20(1), 1381–1388.
32. Liwani, U. 2017. Effect of water stress imposed at tillering, flowering and grain filling in irrigated wheat (*Triticum aestivum* L.) genotypes. Masters Dissertation: 85.
33. Liwani, U., Magwaza, L.S., Odindo, A.O., and Sithole, N.J. 2019. Growth, morphological and yield responses of irrigated wheat (*Triticum aestivum* L.) genotypes to water stress. Acta Agriculturae Scandinavica, Section B – Soil & Plant Science, 69(4), 369–376.
34. Maleki, A., Naderi, A., Naseri, R., Fathi, A., Bahamin, S., Maleki, R. 2013. Physiological performance of soybean cultivars under drought stress. Bulletin of Environment, Pharmacology and Life Sciences, 2(6), 38–44.
35. 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).
36. Rana, M.S., Hasan, M.A., Bahadur, M.M., and Islam, M.R. 2017. Physiological evaluation of wheat genotypes for tolerance to water deficit stress. Bangladesh Agronomy Journal, 20(2), 37–52.
37. Raza, M.A.S., Zulfiqar, B., Iqbal, R., Muzamil, M.N., Aslam, M.U., Muhammad, F., Habib-ur-Rahman, M. 2023. Morpho-physiological and biochemical response of wheat to various treatments of silicon nano-particles under drought stress conditions. Scientific Reports, 13(1), 2700.
38. Reynolds, P., Ortiz-Monasterio J., McNab A., Reynolds E.M. and Reynolds, M. 2019. Application of Physiology in Wheat Breeding.
39. Sharma, V., Bhambota, S. 2022. Strategies to Improve Crop-Water Productivity. In Food, Energy, and Water Nexus: A Consideration for the 21st Century 149–172. Cham: Springer International Publishing.
40. Sharma, V., Rai, A. 2022. Dry bean (*Phaseolus vulgaris* L.) crop water production functions and yield response factors in an arid to semi-arid climate. Journal of the ASABE, 65(1), 51–65.
41. Shrief, S.A., and Abd El-Mohsen, A.A. 2015. Regression models to describe the influence of different irrigation regimes on grain yield and water use efficiency in bread wheat. Advance in Agriculture and Biology, 4(1), 39–49.
42. Siyal, A.L., Siyal F.K. and Tahira Jatt,T. 2020. Yield from genetic variability of bread wheat (*Triticum aestivum* L.) genotypes under water stress condition: A case study of Tandojam, Sindh. Pure and Applied Biology. 10(3), 841.
43. Zadoks, J.C., Chang, T.T., and Konzak, C.F. 1974. A decimal code for the growth stages of cereals. Weed Research, 14(6), 415–421.
44. Zein, A.K. 2002. Rapid determination of soil moisture content by the microwave oven drying method. Sudan Engineering Society Journal, 48(40), 43–54.