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RESPONSE OF OAT (*AVENA SATIVA* L.) GROWTH AND PRODUCTION TO WATER STRESS CONDITIONS

Z.S. AL-DULAIMI* and M.J. ALI

Department of Field Crops, Agriculture College, Al-Qasim Green University, Iraq
Corresponding author's emails: zamansalah@agre.uoqasim.edu.iq
Email address of co-author: mohammad.jasim@agre.uoqasim.edu.iq

SUMMARY

The conduct of a field trial on oat (*Avena sativa* L.) transpired during the crop season of 2020–2021 at the District Seddat Al-Hindiyya, Al-Mahnawiyah region, Babylon Governorate, Iraq. The latest study aimed to evaluate oat cultivars' response based on their growth and yield under water stress conditions and identify the drought-tolerant genotypes. The experiment in a randomized complete block design (RCBD) had a split-plot arrangement, two factors, and three replications. The main plots included three levels of water stress, i.e., depletion of available water by 50% (D1), 60% (D2), and 70% (D3), while the sub-plots included four oat cultivars, namely, Shefa'a, Oats-11, Gouda, and Carlop. The results showed the control treatment (with 50% depleted available water) proved superior in oat growth and related traits, i.e., plant height, flag leaf area, chlorophyll content, relative water content, panicles m^2, seeds per panicle, 1000-seed weight, and grain yield with averages, reaching 98.76 cm, 43.78 cm^2, 48.58 SPAD, 77.24%, 631.5 panicles m^{-2}, 61.17 grains $panicle^{-1}$, 42.94 g, and 16.11 t ha^{-1}, respectively, compared with the D3 irrigation treatment, with values for above traits showed a significant decline: 93.97 cm, 30.05 cm^2, 34.47 SPAD, 65.75%, 340.3 panicles m^{-2}, 46.42 grains $panicle^{-1}$, 31.51 g, and 4.54 t ha^{-1}, respectively. The oat cultivar Shefa'a was considerably superior, leading the majority of growth and yield traits compared with other cultivars. The results confirmed and recommended growing the oat cultivar Shefa'a under dry and semi-arid environments.

Keywords: Oat (*Avena sativa* L.), cultivars, water stress conditions, drought tolerance, growth and yield traits, physiological parameters

Key findings: The depletion of 50% of available water excelled other water regimes (available water depletion of 60% and 70%) in oat growth and yield-related traits. The oat cultivar Shefa'a also leads in grain yield compared with other cultivars under all the water regimes.

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INTRODUCTION

Oats are widely used food in many different nutritional medicine formulations. It serves therapeutic, preventive, and supplementary dietary treatments for long-term conditions, including cancer and cardiovascular disease. Likewise, it helps control blood sugar and cholesterol levels. Additionally to benefiting blood, oat grains are rich in antioxidant components, especially phenolic compounds (Al-Assadi, 2018). These substances, mainly existing in the grain's outer layer, lessen and prevent chronic illnesses, including heart disease and other ailments. Verardo *et al*. (2011) investigated the possible benefits of oats for lowering blood sugar and cholesterol.

The problem of drought persists in many countries worldwide, often due to climate change, global warming, and the recent decrease in precipitation levels. Moreover, the inadequacies discovered in managing irrigation water exacerbate this problem globally. The previously stated phenomena occur by using agricultural production policies in different contexts. Therefore, because it may significantly affect farming productivity and the economy, it is imperative to investigate thoroughly the many possibilities for addressing these problems. Water shortage, in particular, negatively influences crop growth and development, leading to changes in the plant’s morphological, physiological, and biochemical characteristics. Moreover, it is noteworthy that the magnitude of this effect increases with rising temperatures. Many thermal ranges occur within which the temperature fluctuates, depending on the type of plant and the surrounding environmental conditions at the site (AL-Rubaye, 2022). Drought has become a critical abiotic element that substantially affects the growth and development of the oat crop (Aldulaimi, 2020). Oat varieties have different sensitivity to water limitations due to genetic changes and their interaction with their surroundings.

The range of responses to water scarcity depends upon an individual’s and group’s ability to identify and manage such situations. Detection and response in agricultural plants rely on primary signals reaching the root cells, which trigger generating varied secondary signals. Given these creatures are naturally different, their exposure to water stress causes the activation of the genetic parts that control their defenses. With genetic factors directing this process that differ between varieties, a complete analysis of several types is necessary to decide if they are beneficial in farming areas that are short on water (Wilson *et al*., 2021).

Several studies have found that oat types highly differ in ways that affect their output, such as grain yield, effective floret count, tiller count per unit area, and grain weight. Differences in traits occur because of genetic and environmental factors when filling the grains (Shaker *et al*., 2016). Additionally, this study looked at different oat types to see which ones did best with insufficient water and which are suitable for places likely to experience drought based on their unique qualities.

MATERIALS AND METHODS

During the crop season of 2020–2021, a field experiment materialized in the Babylon Governorate, Iraq (latitude 32.61° North and longitude 44.30° East) to develop and evaluate the oat (*Avena sativa* L.) genotypes under varied water stress circumstances. The experiment used a randomized complete block design (RCBD) with a split-plot arrangement, two factors, and three replications. The main plots comprised irrigation withholding strategies with three water stress conditions, i.e., control treatment D1: available water depletion of 50%, followed by two other stress levels (D2 and D3: available water depletion of 60% and 70%, respectively). The subplots encompass four different oat cultivars: Shefa'a, oats-11, Gouda, and Carlop.

The phosphate (P) fertilizer application continued by incorporating triple superphosphate (45% P_2O_5) into the soil at the rate of 80 kg ha^{-1} before preparing the soil. This study also applied three equal batches of nitrogen. For nitrogen (N), employing the Urea fertilizer (46% N) had a rate of 120 kg ha^{-1}.

Table 1. Physical and chemical properties of the study soil before planting.

Properties	Unit	Value
EC	ds m^{-1}	2.41
pH	-	7.7
Bulk density	Mg m^{-3}	1.32
Moisture at field capacity	-	0.32
Moisture at the point of permanent wilting	-	0.13
Available water	-	0.19

The first batch of nitrogen treatment immediately occurred after emergence, the second batch at the beginning of the tillering stage, and the third at 50% anthesis. The experiment utilized a seed rate of 100 kg ha^{-1}. The soil physical and chemical features assessment proceeded with the sample collection from three distinct places at 0 to 30 cm depths in the experimental area. The soil moisture content evaluation continued at stress levels of 33 and 1500 kPa (Table 1).

Estimating soil moisture content

Using auger helps collect soil samples at 20 and 30 cm depths one day before the irrigation and two days after irrigation. It allowed for an accurate determination of the soil's moisture content. Placing the soil samples in a metal box and weighing the samples continued in a moist condition. After that, to dry the samples, set them in a microwave oven with calibration following the method proposed by Zein (2002). Next, weighing the soil samples again helps calculate the percentage of moisture in the soil samples using the following equation:

$$Ϙv = Ϙw \times \left(\frac{\partial b}{\partial w}\right)$$

Where:

Ϙv = Moisture content based on volume (cm3 cm^{-3})
Ϙw = Moisture content based on weight (g g^{-1})
∂b = Bulk density (g cm^{-3})
∂w = Density of water (g cm^{-3})

Irrigation process

Carrying out irrigation used plastic pipes connected to a fixed-discharge pump (2.1 l s^{-1}) and equipped with a meter to measure the amount of water added to each experimental unit to control the amount of water calculated based on the depletion of the specified water content. Adding equal amounts of water and applying 50% of the available water proceeded to all plots when planting to ensure field emergence. Then, irrigating the plants with 50% (D1), 60% (D2), and 70% (D3) of the available water depleted had a depth of 20 and 30 cm. The amounts of irrigation water for a depth of 20 cm per irrigation for the treatments D1, D2, and D3 were 76, 91, and 107 liters experimental unit^{-1}, while the amount of water for a depth of 30 cm was 114, 137, and 160 liters experimental unit^{-1} for the depletion treatments, respectively. The amount of added water calculation was according to the following equation (Kovda *et al.*, 1973).

$$W = a.As\left(\frac{Pw\%^{F.c} - Pw\%^{w}}{100}\right) \times \frac{D}{10}$$

Where:
W = The volume of water that must be added during irrigation (m^{3})
a = irrigated area (m^{2})
As = bulk density (Mg m^{3})
Pw$^{F.C}$% = Percentage of soil moisture based on weight at field capacity (after irrigation)
Pw^{w}% = Percentage of soil moisture before irrigation
D = Soil depth at desired root total (cm)

Studied attributes

Plant height (cm) estimation used a metal measuring tape from the soil surface to the base of the flower inflorescence of the main stem. Flag leaf area (cm^2) estimates were according to the following equation (Thomas, 1975):

$$\text{Flag leaf area} = \text{flag leaf length} \times \text{maximum width} \times \text{correction factor (0.75)}$$

Chlorophyll content (SPAD) estimation used a Japanese Chlorophyll Meter SPAD Model-502 by taking three readings for each flag leaf of the random plant samples. For relative water content (RWC %), the collected several newly cut flag leaves reached sealing in nylon bags to avoid any loss of moisture, then weighed immediately for preparation. Following this was the immersion of leaves in distilled water for 12 to 14 hours while being illuminated and kept at room temperature. After that, the leaves used filter paper for drying, weighing to reflect the whole weight, and then placed in an oven at 85 °C until the weight was stable. After obtaining the dry weight of the leaves, the following equation helped measure the RWC (%) (Barnes and Woolley, 1969).

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

Where:
R.W.C = relative water content
FW = fresh weight (g)
DW= dry weight (g)
TW = Total weight (g)

The panicle m^{-2} calculation occurred at the 100% flowering stage by taking a random sample from the middle rows of half a meter and then proportioning it to a square meter. Computing the grains per panicle continued for a random sample of 10 panicles taken from the middle rows of each experimental unit. The 1000-grain weight (g) came randomly from the grain yield of each experimental unit and weighed. The grain yield (tons ha^{-1}) attained calculation for a specific harvested area and then converted to tons ha^{-1}.

Statistical analysis

The data analysis employed the analysis of variance (ANOVA) according to the RCBD design with a split-plot arrangement in the Genstat program and the arithmetic means of the coefficients comparison using the least significant difference ($LSD_{0.05}$) test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Plant height

The results revealed that irrigation regimes, oat cultivars, and their interaction significantly affect plant height (Table 2). The D1 stress treatment (depletion of 50% available water) was significantly superior for plant height (98.76 cm) compared with the D3 treatment (depletion of 70% available water) (93.97 cm). The findings also indicated meaningful interaction effects between the irrigation treatments and oat cultivars. According to Shirazi *et al*. (2014), insufficient water availability causes a drop in the water potential of plant cells, which, in turn, causes a decrease in the rate of plant cell division and elongation.

Comparing the oat cultivars, the oat cultivar Shefa'a was much superior for the said trait (97.56 cm), whereas the cultivar Oat-11 showed the lowest average for the plant height (95.52 cm). These differences may refer to the possible genetic diversity and variations in the intermodal length among the oat genotypes. Under water stress conditions and in different genotypes, similar variations were evident for the trait (Abd-El-Rady and Koubisy, 2023).

Flag leaf area

The findings demonstrated significant differences among the irrigation regimes, oat cultivars, and their interactions for flag leaf area (Table 3). The D1 irrigation treatment was superior, recording the highest average flag leaf area (43.78 cm^2) compared to the D3 irrigation treatment (30.05 cm^2). The oat cultivar Shefa'a produced the maximum average for this attribute (40.13 cm^2)

Table 2. Effect of cultivars, irrigation treatments, and their interaction on the oat's plant height.

Cultivars	Irrigations			Means (cm)
	D1	D2	D3	
Shefa'a	99.50	98.10	95.10	97.56
Oats 11	98.13	95.53	92.90	95.52
Gouda	98.87	97.60	94.37	96.94
Carlop	98.53	97.33	93.50	96.46
Means (cm)	98.76	97.14	93.97	
$LSD_{0.05}$ Cultivars = 0.24, Irrigations = 0.22, C × I = 0.39				

Table 3. Effect of cultivars, irrigation treatments, and their interaction on the oat's leaf area.

Cultivars	Irrigations			Means (cm^2)
	D1	D2	D3	
Shefa'a	48.50	36.70	35.20	40.13
Oats 11	40.13	35.30	24.77	33.40
Gouda	43.60	38.80	31.07	37.82
Carlop	42.87	37.17	29.17	36.40
Means (cm^2)	43.78	36.99	30.05	
$LSD_{0.05}$ Cultivars = 1.74, Irrigations = 1.93, C × I = 2.96				

Table 4. Effect of cultivars, irrigation treatments, and their interaction on the oat's leaf chlorophyll content.

Cultivars	Irrigations			Means (SPAD)
	D1	D2	D3	
Shefa'a	53.33	53.03	35.33	47.23
Oats 11	52.23	52.27	35.07	46.52
Gouda	45.40	45.30	34.67	41.79
Carlop	43.33	43.20	32.80	39.78
Means (SPAD)	48.58	48.45	34.47	
$LSD_{0.05}$ Cultivars = 1.09, Irrigations = 0.65, C × I = 1.69				

compared with the cultivar Oats-11 (33.40 cm^2). According to Saeidi and Abdoli (2015), the flag leaf area across these types may be attributable to the fact that these cultivars have distinctly different genetic makeup and varied levels of susceptibility to drought. The interaction between the oat cultivars and the irrigation treatments also demonstrated substantial differences. Past studies revealed that the decline in leaf area was due to the crop's subjection to water stress, degrading the elongation rate of plant cells (Ali and Akmal, 2022; Al-Yasari, 2022).

Chlorophyll content

Notable differences existed among the irrigation regimes, oat cultivars, and their interaction (Table 4). The D1 irrigation treatment outperformed the D2 irrigation treatment (depletion of 60% available water) with a nonsignificant difference (48.58 and 48.45 SPAD, respectively), compared with the D3 irrigation treatment, which showed the lowest average (34.47 SPAD). The decrease in chlorophyll content due to severe stress conditions may be because chlorophyll is a primary component of plastids for photosynthesis, sustaining adverse effects from drought stress (AL-Rubaye, 2022). Cultivar Shefa'a has a significantly higher level of chlorophyll pigment (47.23 SPAD) than the Oat-11 (46.52 SPAD), while the oat cultivar Carlop had the lowest level of chlorophyll pigment (39.78 SPAD) (Table 4). These cultivars' variation in chlorophyll content may be due to differences in the genotypes' genetic makeup and their response to water stress conditions (Saeidi *et al*., 2015; Alshadiwi and Alrubaiee, 2022).

Relative water content

Significant differences emerged among the irrigation regimes and the oat cultivars, while their interactions were nonsignificant for relative water content (RWC) (Table 5). The D1 irrigation treatment (77.24%) was leading for relative water content; however, it did not have a significant difference with the D2 irrigation treatment (76.76%), and the minimum value for the said trait was evident in the D3 irrigation treatment (65.75%). It may be due to a decrease in the water potential of the soil, which, in turn, decreases the plant's ability to absorb more water. The reduction in relative water content may refer to a decline in the water potential of the soil (Zareian *et al*., 2014).

The oat cultivars also differed for the relative water content. The oat cultivar Shefa'a was significantly superior (76.21%) but was nonsignificantly different from the oat cultivar Gouda (75.31%), compared with the cultivar Carlop, having the lowest average for the said trait (69.11%) (Table 5). This variation in relative water content might be due to the difference in the cultivars' genetic diversity based on physiological variations (Li *et al*., 2019).

Panicles m^{-2}

For the number of panicles m^{-2}, irrigation treatments revealed significant differences, while the oat cultivars and their interaction with irrigation enunciated nonsignificant variations for the said trait (Table 6). An observation also indicated that the number of panicles decreases with increasing stress conditions, and the D1 irrigation treatment was significantly superior to the rest of the treatments, with an average of 631.5 panicles m^{-2}, compared with the D3 irrigation treatment (340.3 panicles m^{-2}). The decrease in the number of panicles due to water stress may be due to the drought effects influencing growth traits and, eventually, yield-related features (Liwani *et al*., 2019).

Grains per panicle

For grains per panicle, marked differences occurred among the irrigation regimes, oat cultivars, and their interactions (Table 7). The D1 irrigation treatment was significantly superior, with an average of 61.17 grains panicle-1, compared with the lowest average recorded in the D3 irrigation treatment (46.42 grains panicle-1). The fact that water stress causes a decrease in the photosynthesis process increases the competition among the tillers and hurts the number of spikelets that survive. The reduced grain per panicle may refer to the fact that water stress causes a decline in growth and, eventually, affects yield-related traits. Mwadzingeni *et al*. (2016) also mentioned that water stress might affect the process of pollination and fertilization of florets, leading to the sterility of pollen grains during the blooming stage and a subsequent reduction in the number of grains per panicle.

The oat cultivar Shefa'a produced the highest average at 58.57 grains panicle^{-1} compared with the cultivar oats-11, which gave the lowest average (48.72 grains panicle^{-1}). It is due to the variation in cultivars for this trait brought about by the deviation in the degree of their sensitivity to water deficiency, reflecting negatively or positively in the number of grains per panicle (Sarwar *et al*., 2023).

1000-grain weight

Significant differences appeared among the irrigation treatments, oat cultivars, and their interactions for 1000-grain weight (Table 8). The D1 irrigation treatment was remarkably superior, with an average 1000-grain weight of 42.94 g, compared with the D3 irrigation treatment, with the lowest average for the said trait (31.51 g). In terms of 1000-grain weight (39.12 and 38.71 g, respectively), the oat cultivar Gouda outperformed the cultivar Shefa'a with nonsignificant differences. With a grain weight of 33.48 g, the cultivar oats-11 had the minimum average.

Table *5*. Effect of cultivars, irrigation treatments, and their interaction on the oat's leaf relative water content (percentage).

Cultivars	Irrigations			Means (%)
	D1	D2	D3	
Shefa'a	80.37	79.77	68.49	76.21
Oats 11	76.27	75.97	64.91	72.38
Gouda	79.48	78.75	67.70	75.31
Carlop	72.87	72.55	61.92	69.11
Means (%)	77.24	76.76	65.75	
$LSD_{0.05}$ Cultivars = 1.05, Irrigations = 0.78, C × I = N.S.				

Table 6. Effect of cultivars, irrigation treatments, and their interaction on the oat's panicles per meter square.

Cultivars	Irrigations			Means (panicles m^{-2})
	D1	D2	D3	
Shefa'a	642.0	471.7	340.0	484.6
Oats 11	631.0	472.3	341.7	481.7
Gouda	627.0	467.7	339.3	478.0
Carlop	626.0	463.3	340.0	476.4
Means (panicles m^{-2})	631.5	468.8	340.3	
$LSD_{0.05}$ Cultivars = N.S., Irrigations = 64.89, C × I = N.S.				

Table 7. Effect of cultivars, irrigation treatments, and their interaction on the oat's grains per panicle.

Cultivars	Irrigations			Means (grains $panicle^{-1}$)
	D1	D2	D3	
Shefa'a	65.00	59.20	51.50	58.57
Oats 11	58.33	49.43	38.40	48.72
Gouda	61.27	58.33	49.50	56.37
Carlop	60.07	53.13	46.30	53.17
Means (grains $panicle^{-1}$)	61.17	55.02	46.42	
$LSD_{0.05}$ Cultivars = 1.07, Irrigations = 1.46, C × I = 1.94				

Table 8. Effect of cultivars, irrigation treatments, and their interaction on the oat's 1000-grain weight.

Cultivars	Irrigations			Means (g)
	D1	D2	D3	
Shefa'a	43.57	38.20	34.37	38.71
Oats 11	41.50	34.80	24.13	33.48
Gouda	44.03	38.87	34.47	39.12
Carlop	42.67	36.43	33.07	37.39
Means (g)	42.94	37.07	31.51	
$LSD_{0.05}$ Cultivars = 1.61, Irrigations = $LSD_{0.05}$ C × I = 2.77				

Table 9. Effect of cultivars, irrigation treatments, and their interaction on the oat's grain yield.

Cultivars	Irrigations			Means (t ha^{-1})
	D1	D2	D3	
Shefa'a	17.68	10.18	5.51	11.13
Oats 11	14.77	7.64	2.66	8.36
Gouda	16.45	10.13	5.28	10.62
Carlop	15.54	8.48	4.70	9.58
Means (tons ha^{-1})	16.11	9.11	4.54	
$LSD_{0.05}$ Cultivars = 0.35, Irrigations = 1.88, C × I = 1.83				

The cause may be due to genetic differences and their reaction to the water stress circumstances. According to Zhang *et al.* (2018), oat cultivars more susceptible to water stress saw higher effects than cultivars less susceptible, particularly during the grain-filling stage, leading to a decrease in 1000-grain weight. With water stress, which stops nutrients and water from getting to the grains during their filling stage and causes the grains to contract and get smaller, the weight of a thousand grains reduces (Maqbool *et al*., 2015).

Grain yield

The interactions between the genotypes of oats and the irrigation schedules caused significant differences in grain yield (Table 9). The D1 irrigation treatment yielded the highest average grain production of 16.11 t ha^{-1}, significantly outperforming the other treatments. In contrast, the D3 irrigation treatment generated the lowest average grain production of 4.54 t ha-1. The results showed that reduction in yield factors like panicles m^2, grains per panicle, and 1000-grain weight may have caused a drop in food production during droughts (Tables 6, 7, and 8). The detrimental impacts of water stress on several growth metrics, including relative water content, chlorophyll content, plant height, and flag leaf area (Tables 2, 3, 4, and 5), may also help to explain this. These results aligned with previous studies that indicated the grain experienced less drought (Hafez and Seleiman, 2017).

In the case of oat cultivars, the cultivar Shefa'a was much superior, leading in grain yield (11.13 t ha^{-1}) compared with the cultivar Oats-11, which delivered the lowest average grain yield (8.36 t ha^{-1}). Hussain *et al*. (2023) also suggested that the reduced grain yield could refer to cultivar decline in its growth characteristics and yield components, which primarily manage the grain yield.

CONCLUSIONS

Based on the results, it can be inferred that oat cultivars exhibited varying performance by subjecting to the water stress conditions. The study revealed that the oat cultivar Shefa'a demonstrates a notable capacity for the better growth and yield traits, and adaptation to the water-deficient conditions. Consequently, it is advisable to grow the cultivar Shefa'a in regions characterized by aridity and semi-aridity.

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