

ARTICLE

Impacts of Water-Stress and Proline on the Physiological, Growth, and Yield of Sunflower (*Helianthus annuus* L.)

Zaman Salah Al-Dulaimi¹, Firas Abdul Karim Makki Al-Gharawi², Sajdeen Hayder Hatim³,
Salam Ali Abdul Hussein Al-Masoudi⁴, Mohammed Fadhil noori Alsharifi⁵

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

² Department of Civil Engineering, College of Engineering, Al-Qasim Green University, Babylon, Iraq

³ Department of College of Science, University of Babylon, Babylon, Iraq

⁴ Department of Field Crops, Agriculture College, Al-Qasim Green University, Babylon, Iraq

⁵ Department of Field Crops, Agriculture College, Al-Qasim Green University, Babylon, Iraq

ABSTRACT

This study was planned to decrease spraying-water use in sunflower (*Helianthus annuus* L.) submerged-required environments and to manifest the significance of proline in alleviation damage associated with water imperfection. The 1-Factor filling a place the main plots incorporated water-required situation; S1 (control: exhaustion of 50% of vacant water) and S2, S3, and S4 (interpreting 75, 60, and 40% of the water bulk used in the S1, individually). The 2-determinant design was filling a place the substitute-plots for foliar request accompanying concentrations of proline at 0% (control), 20, 40, and 60 mg/L⁻¹. The observations explained that the S1 and S2 water-stress situations outperformed the added determinants, and no important distinctness 'tween bureaucracy, across various calculated limits, containing leaf extent, net photosynthesis rate, sunflower plate width, productivity%, number children-disc, and last yield. The particular wealth of limits was: 4.820 and 4.763 cm²; 3.891 and 3.878 g m⁻² era⁻¹; 16.977 and 16.357 cm; 91.96% and 91.61%; 640.92 and 633.10 children; and 3.76 and 3.66 t ha⁻¹ for S1 and S2, individually. In contrast, the S4 water-required situation allowed the minimum mean principles for all studies calculated traits. Regarding the proline concentrations secondhand, the 60 mg/L⁻¹ outperformed the added determinant for most measured traits, except that net photosynthesis, pregnancy allotment, beginning number, and ending children yield, place it acted not vary considerably from the 40 mg/L⁻¹ aggregation, while the control situation (0 mg/L⁻¹) happened in the minimum mean principles for all studies calculated traits. Proline importance as an osmolyte display or take public alleviation the damage all along water-stress in plants through a tenable approach.

Keywords: Sunflower; Water-stress; Proline; Physiological Parameters.

Corresponding Author: Zaman Salah Al-Dulaimi

E-mail: zamansalah@agre.uoqasim.edu.iq

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INTRODUCTION

The significance of the sunflower (*Helianthus annuus* L.) is due to its seeds which are 55% oil and contain about 14% of total global oil production. Sunflower seeds, besides rapeseed and soybean, are among the main sources of oil production in the world (Petrenko *et al.*, 2023). Sunflower oil is therefore considered to be one of the preferred cooking oils because of its high level of specific fatty acids such as oleic acid, linoleic acid (omega-6) and palmitic acid (Adeleke and Babalola, 2020). In industrial use, seed-sunflower oil is used as raw material for soap making (Chen and Liu, 2025).

In addition, the seed residues (oil cake) after oil extraction are rich in protein (up to 40%) and Carbohydrates (up to 20%) and thus can be used as nutritious supplements for livestock and poultry feeds (Al-Awda *et al.*, 2009). Surface irrigation farming may not have strategies to deal with water shortage, especially in newly reclaimed farmlands (Zheng *et al.*, 2024). Optimizing the irrigation management is therefore a sustainable solution to preventing excessive irrigation water consumption, and cultivation of drought-tolerant crops is also a sustainable solution that can improve the growth and yield of crops (Chen *et al.*, 2023). Although the climate in the central part of the country is semi-arid, sunflower cultivation once covered a large area and had a high level of local production (Abas *et al.*, 2025).

Due to the global climate change, central Iraq has faced insufficient rainfall, excessive irrigation water use because of the lack of agricultural monitoring and the growth of population for irrigation water use (Salman *et al.*, 2020). Besides, water policies of the countries sharing Iraq's river basins have resulted in a considerable decrease in the volume of river water available for Iraq. The availability of irrigation water is the constraint for expanding agricultural land base, therefore, coordinating and optimizing the water use of irrigation water is needed to avoid the further aggravation of the situation.

The strategies involve establishing water reservoirs (such as lakes), optimizing the use of irrigation water in agriculture, finding and developing technologies to reduce water losses, and cultivating drought-tolerant crop varieties (Al-Dulaimi *et al.*, 2024). Physiological changes in plant reflect the water-stress level in their environment, e.g., stress generally affects physiological functions which are detrimental to productivity. In sunflowers, it has been found that the extent of damage caused by water stress is closely related to the proline content of the plant which is a free amino acid found in plant tissue (Alhilali, 2005). Under water-stress conditions, proline plays a role in osmotic adjustment; regulates water uptake and the flow of electrolytes from neighbouring root cells by stabilizing membranes and maintaining continuous cell turgor (Hayat *et al.*, 2012; Sleibi and Abdullah, 2025).

In recent years, the application of exogenous proline was found to be a sustainable, biological method to alleviate water-stress has gained the interest of researchers. The purpose of the recent study was to evaluate the growth indicators of sunflower crop under limited water availability and irrigation water use regulation and to test the role of proline as osmolyte regulator in minimizing the damages caused by water-stress.

MATERIALS AND METHODS

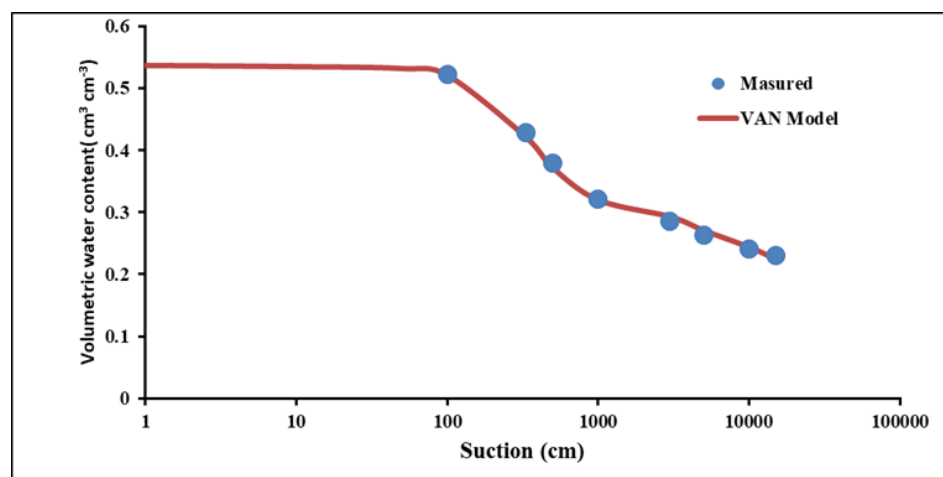
Details of Trial

A field trial was conducted at the farmer's field in the Babylon Governorate in central Iraq, during 2026 growth season. In this study, sunflower was chosen to minimize the usage of water for irrigation and to provide proof as to the role of Proline as an osmolyte in mitigating damage caused by water deficiency. Randomized Complete Block Design (RCBD) split-plot design with 3-replicates was used. The main plots of the 1-factor were water-stress treatments: S1 (untreated control, irrigation when 50% of available water is depleted); S2 75% of the water quantity applied to S1; S3 60% of the water quantity applied to S1; and S4 45% of the water quantity applied to S1. These were allocated to the sub-plots with foliar application of the 2-factor (0% (control), 20, 40 and 60 mg/L⁻¹) of proline. For the evaluation of the physic-chemical characteristics (Table 1), random soil samples were taken from different locations at a depth of 50 cm.

Table (1) Physic-chemical characteristics of the studied-field soil

Characteristic		Value
Separates-soil		48
		30
		22
pH		7.72
EC(ds/m ⁻¹)		2.7
Texture-soil		Loam-Clay-Sandy
Density (mg/m ³)		1.32
Elements-available /ppm	N	25.32
	P	7.3
	K	207
Matter-organic (OM %)		1.5
Capacity-field		0.422
Wilting point-permanent (cm ⁻³)		0.217
Water-available		0.205

The soil was tilled and pulverized as per scientific practice and the plots used for experiments were of 12 m² (3 m × 4 m). Row length: 3m, spacing between the rows: 75 cm, spacing between planting holes: 20 cm. Buffers of size 2 m were installed between the main treatments, 1 m between the sub treatments and 3 m between replicates. Urea fertilizer (46% N) was applied twice, the first application at 4 true leaf emergence and second at flower bud appearance in the young leaves stage at a rate of 340 kg/ha. The tri superphosphate (46% P₂O₅) and Potassium sulfate (41% K) were applied at the rate of 250 kg/ha and 150 kg/ha respectively during land preparation. The experimental areas treated with Treflan-herbicide at 600 cm³/ dunum incorporated into the soil before the layout of the plots to kill weeds associated with sunflower crop. Sunflower-local seeds were sown on 25th February 2026 at 3-4 seed/hole and thinned to 1 seedling/hole after 2 weeks emergence. Hand weeding was done on an as-needed basis. The plants were in physiological maturity on Jun 29, 2026 and were harvested. The relationship between the moisture content and soil matric suction was used to estimate the capacity-soil water retention in the range of 33 to 5000 kPa suction and the available soil water was calculated (Figure 1).

**Figure (1)** curve showing the moisture characteristics of the studied soil

Irrigation-plants Method

The water was carried using plastic pipes with an electric pump providing a fixed discharge rate, the pump was connected to a pipeline and a water meter (calibrated in liters). The same amount of irrigation water was applied at first and second irrigation, which were applied to get the soil to field capacity and to guarantee successful germination. Treatment with water-deficit was started at the third irrigation.

Measurement of field soil moisture content

The water was carried using plastic pipes with an electric pump providing a fixed discharge rate, the pump was connected to a pipeline and a water meter (calibrated in liters). The same amount of irrigation water was applied at first and second irrigation, which were applied to get the soil to field capacity and to guarantee successful germination. Treatment with water-deficit was started at the third irrigation.

$$PW\% = \frac{MW-DW}{DW} \times 100 \quad (1)$$

Where: PW% = moisture content on dry-weight basis, MW= wet weight (g), and DW= dry weight (g)

Irrigation continued once 50% of water-available was depleted; soil moisture was monitored and replenished to capacity-field using the equation proposed by [Kohnke \(1968\)](#).

$$W = a \cdot Bd \left(\frac{\% PW^{f.c} - \% PW^m}{100} \right) \times D \quad (2)$$

Where: W= water volume to be added at irrigation (m³), a= Irrigation rate (m²), Bd= Bulk density (mg/m³), PW^{f.c}= Soil moisture% by weight at capacity-field (post-irrigation), PW^m= Soil moisture% by weight pre-irrigation, and D= Soil depth (m).

Studies Plant calculated traits

1. Leaf Area (cm²)

Leaf area was calculated by measuring the maximum leaf width and multiplying the square of the width by the constant 0.65 according the approach described in [Elsahookie and Eldabas \(1982\)](#).

$$L.A = 0.65 \sum W^2 \quad (3)$$

Where: L.A= Leaf area, and W= leaf width.

2. Crop Growth Rate

Crop growth was driven as (g m⁻² era⁻¹) utilizing the following equation, in accordance with Al-Muaini and Al-Ubaidi (2018).

$$CGR = \frac{1}{P} \times \frac{W2-W1}{T2-T1} \quad (4)$$

Where: CGR= crop growth rate, P= land area occupied by the plant, W1= Initial sample weight (pre-appearance of discs), W2= Final sample weight (pre-harvest), T1= Time of initial sampling (day), and T2= Time of final sampling (day).

3. Relative Growth Rate

The relative growth was driven as (g g⁻² era⁻¹) utilizing the following equation, in accordance with [Al-Muaini and Al-Ubaidi \(2018\)](#).

$$RGR = \frac{\ln W2 - \ln W1}{T2-T1} \quad (5)$$

Where: RGR= Relative Growth Rate, and Ln= Natural logarithm

4. Net Photosynthesis

The net assimilation was persistent as (g m⁻² epoch⁻¹) utilizing the following equating, following [Al-Muaini and Al-Ubaidi \(2018\)](#).

$$\text{NAR} = \frac{(W2-W1)(\ln LA2 - \ln LA1)}{(T2-T1)(LA2-LA1)} \quad (6)$$

Where: NAR= Net Assimilation Rate, LA1= Leaf area at sampling pre-disc emergence, LA2= Leaf area at sampling pre-harvest, and Ln= Natural logarithm.

5. Disc diameter (cm)

The average was determined from ten accumulated plant and calculated at the division holding the plate florets at adulthood, following [Knowles \(1978\)](#).

6. Fertilization rate %

The Fertilization% was determined by accumulating a 50 g random sample from each exploratory plot, and the following equating was used agreement accompanying [Al-Rawi \(1983\)](#).

$$\text{Fertilization \%} = \frac{NFS}{NES+NFS} \quad (7)$$

Where: NFS= Number of filled seeds, and NES= Number of empty seeds.

7. Seed Number in Disc

The number of seeds per disc was evaluated by wily the average for ten discs per situation, adding only suffused sources.

8. Weight of 100 seed (g)

Filled seeds were randomly picked from the seed yield of each exploratory plot and burden utilizing a delicate photoelectric balance.

9. Seed Yield

Seed yield (t ha^{-1}) was premeditated utilizing the following equation: Seed yield= Average source yield per situation $\times$ Plant mass. The burden was used to a dampness content of 8% agreement accompanying [Alsahooke \(1994\)](#).

Statistics analysis

The soil data were resolved post-selection and table utilizing the ANOVA (Analysis of Variance) plan by way of the GenStat V.20 mathematical program, following the process characterized by [Al-Asadi \(2019\)](#). The mean correspondings were acted utilizing the Least Significant Difference (LSD) test at a (0.05) similarly [Al-Rawi and Khalaf Allah \(2000\)](#).

RESULTS AND DISCUSSION

Plant leaf Area

Data summarized in Table (2) pointed out meaningful differences in intentional characteristic between water-required situation, proline application levels, and their interplay. It was noticed that the prepared control for water-stress (S1) caused the chief value appearance no important dissimilarity from situation S2 accompanying an average of 4820 cm^2 . In contrast, treatment S4 had the minimal mean profit (3099 cm^2), appearance no important distinctness from S3. This response maybe made clear by water-stress impairs or limits container turgor and extension, superior to reduced container breadth all along the herbaceous development stage, as report by [Al-Rubaie \(2022\)](#). The verdicts also granted that a proline reveal at 60 mg/L^{-1} an raised leaf district (5901 cm^2), while the control leaves (0 mg/L^{-1}) allowed the lowest average (2648 cm^2).

Proline acts as multifunctional securing; it expedites natural osmoregulation and scavenges free radicals, through keeping enzymes and cell membranes and maintaining plant leaf field worn out-environments (Al-Rubaie, 2021). Furthermore, the Table (2) marked that the interaction betwixt situation S1 and proline at 60 mg/L⁻¹ granted meaningful advantage with an average of 6647 cm², that acted not vary important from the interplay (S2 and 60 mg/L⁻¹), compared to the interplay of (S4 and 0 mg/L⁻¹), that shown the minimum mean of 1992 cm² and likewise acted not differ considerably from the interplay of (S3 and 0 mg/L⁻¹).

Table (2) Impact of water-stress and Proline concentrations and their interactions on leaf area (cm²)

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	3310	4220	5105	6647	4820
S2	3290	4210	4937	6616	4763
S3	2000	3091	3320	5929	3585
S4	1992	2991	3000	4413	3099
Average	2648	3626	4090	5901	
LSD (0.05)	Water-stress levels= 61.66		Proline concentration = 82.00		Interaction = 120

Crop Growth (g m⁻² day⁻²)

Data presented in Table (3) registered significant belongings of stress situations and proline concentrations, in addition to their interaction, on this characteristic. The notes showed that (S1) treatment written a considerably taller profit than the other situations, accompanying an average of 13.56 g m⁻² epoch⁻¹, while treatment (S4) had the minimal mean advantage of 10.25 g m⁻² epoch⁻¹. A possible clarification is that water inadequacy reduces the plants development and development ending, through decreasing photosynthetic output; this in another way impacts dry matter accretion, as a consequence, this characteristic (Kadhim, 2023). These findings likewise illustrated the meaningful superiority of the 60 mg/L⁻¹ accompanying mean of 14.23 g m⁻² era⁻¹, while the 0 mg/L⁻¹ in prepared control had the smallest mean worth of 8.96 g m⁻² epoch⁻¹. This climaxes the effective gift of proline in lowering osmotic stress inside plant cells, speeding root endeavor in water and fiber uptake. These, in proper sequence, claim container turgor and block stomatal closure, through exciting alive plant processes such as formation of cells by dividing and extension, specifically under water-required environments, that contributes absolutely to dry matter burden (Al-Dulaimi, 2024). Furthermore, the interplay between of (S1 and 60 mg/L⁻¹ of proline) written a considerably taller worth than the others, accompanying mean of 16.41 g m⁻² era⁻¹ while the interplay between (S4 and 0 mg/L⁻¹ of proline) written shortest advantage with average was 7.97 g m⁻² era⁻¹.

Table (3) Impact of water-stress and proline levels and their interactions on crop growth rate (g m⁻² day⁻²)

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	8.51	12.52	15.81	16.41	13.56
S2	9.97	12.51	14.82	15.41	13.17
S3	8.41	10.8	13.61	13.32	11.58
S4	7.97	9.81	11.22	11.81	10.25
Average	8.96	11.50	13.86	14.23	
LSD (0.05)	Water-stress levels= 0.90		Proline concentration =0.47		Interaction = 0.54

Relative Growth

The values in Table (4) presented significant effect of water-required situation, proline concentrations, and their interplays on this characteristic. The remarks demonstrated that situation (S1) written a considerably greater value than the additional concerning this characteristic, record 0.0107 g g⁻¹ era⁻¹, compared to situation (S4), that had the minimal mean

profit of 0.0062 g g⁻¹ epoch⁻¹. Water deficiency reduces plant container turgor pressure, a basic cause of ready to bear tumor and development, as water required decreases container capacity and reduces container wall stretchiness (Hessini *et al.*, 2009). Furthermore, uncovering to water-stress brings about the release of Absciscic acid; allure translocation to the leaves causes stomatal plug and slows herbaceous tumor, with unfavorably impacting this characteristic (Zhao *et al.*, 2020). The results acquired too illustrated that the proline at 60 mg/L⁻¹ recorded a considerably greater advantage than the remainder of something, accompanying an average of 0.0131 g g⁻¹ day⁻¹, while the 0 mg/L⁻¹ (plants control) surrendered the minimum mean (0.0063 g g⁻¹ epoch⁻¹). Proline has an main function in plant container osmoregulation, maintaining turgor pressure by easing water rude answer; this keeps stomata open and experiences adept photosynthesis, with improving herbaceous development (Khan *et al.*, 2025).

Additionally, proline acts as an antioxidant and free-radical collector, insulating the photosynthetic apparatus form oxidative damage (Fathi *et al.*, 2025). This embellishes the plants capability to produce sugars and protect strength, thereby definitely moving this characteristic (Andrade *et al.*, 2021). The results also presented that the interplay middle from two points of (S1 and proline at 60 mg/L⁻¹) written a considerably higher profit than the remainder of something, accompanying an average of 0.0181 g g⁻¹ era⁻¹, while the interplay between of (S4 and proline at 0 mg/L⁻¹) had the minimal mean profit of 0.0053 g g⁻¹ era⁻¹.

Table (4) Impact of water-stress, proline concentrations, and their interactions on relative growth rate (g g⁻¹ day⁻¹)

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	0.0071	0.0083	0.0091	0.0181	0.0107
S2	0.0068	0.0079	0.0089	0.0178	0.0104
S3	0.0061	0.0069	0.0084	0.0101	0.0079
S4	0.0053	0.0060	0.0071	0.0064	0.0062
Average	0.0063	0.0073	0.0084	0.0131	
LSD (0.05)	Water-stress levels= 0.00017 Proline concentration = 0.00015 Interaction = 0.00025				

Net Photosynthesis

Table 5 shows important effect of water-stress determinant, proline concentrations and their interactions on net photosynthesis characteristic. Factors S1 and S2 outperformed the remainder of something, accompanying no significant distinctness betwixt ruling class, flexible means of 3.891 and 3.878 g m⁻² era⁻¹, individually. In contrast, determinant S4 had the smallest mean profit (2.229 g m⁻² epoch⁻¹); water-stress impels plants to close their stomata to prevent dissolution and water misfortune, an answer that prevents photosynthesis and reduces biomass accumulation, through otherwise moving this trait. The table further disclosed that the spray of proline at concentrations of 60 and 40 mg/L⁻¹ acted significantly better, accompanying no important dissimilarity betwixt them, flexible method of 3.661 and 3.624 g m⁻² era⁻¹, respectively, meantime, the control situation of 0 mg/L⁻¹ presented the minimum mean (2.604 g m⁻² epoch⁻¹). The results exhibited that the interplay determinant S1 linked with proline at concentrations of 60 and 40 mg/L⁻¹, accompanying method of 4.419 and 4.409 g m⁻² epoch⁻¹, respectively, acted not vary considerably from the interplay between the determinant S2 connect accompanying proline at 40 mg/L⁻¹. While the interaction determinant of (S4+ 0 mg/L⁻¹ and S4+ 20 mg/L⁻¹) allowed hostile means (2.009 and 1.999 g m⁻² epoch⁻¹, individually, that acted not differ considerably from the interplay determinant of (S3+ 0 mg/L⁻¹ and S3+20 mg/L⁻¹). The findings rooted and supported the alive contribution of proline inside plastids, place it protects proteins and enzymes from damage and gelatin chlorophyll pigments submerged-deficit environments, through improving photosynthetic efficiency (Cechin *et al.*, 2006).

Table (5) Impact of water-stress, proline concentrations, and their interactions on net photosynthesis

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	3.208	3.529	4.409	4.419	3.891
S2	3.198	3.508	4.398	4.408	3.878
S3	1.999	2.009	3.278	3.308	2.649
S4	2.009	1.999	2.410	2.508	2.229
Average	2.604	2.761	3.624	3.661	
LSD (0.05)	Water-stress levels= 0.106 Proline concentration = 0.104 Interaction = 0.016				

Disc Diameter

The remarks designated a meaningful distinctness concerning water-stress determinants, proline concentrations, and their interplays on the plate width characteristic (Table 6). The classified results listened that the water-stress factor of S1 a written a considerably bigger worth than the remainder of something in the intentional characteristic, accompanying an average of 16.977 cm, and acted not vary considerably from the determinant S2, while the determinant S4 allowed the minimum mean of 12.521 cm. water imperfection can cause a decline in dry matter build-up on account of a decline in plant corporeal processes; this is apparent in Table 2 and 5, that displayed diminished two together of leaf area and photosynthesis. Collectively, these determinants bring about a decrease in plate width, a characteristic affected by these limits (Salih and Ali, 2026). The reasoning furthermore disclosed that the proline determinant at 60 mg/L⁻¹ written a considerably greater advantage than the remainder of something determinants, accomplishing a mean of 16.488 cm, distinguished to the minimum mean of 13.656 cm noticed in the control situation at 0 mg/L⁻¹. These notes stress an effective gift of proline in plant transport processes, containing the change of water and vitamins to the above parts of the plant (Calero Hurtado *et al.*, 2025). Furthermore, the interplay middle from two points the determinant S1 and proline at 60 mg/L⁻¹ written a considerably greater advantage than the different situations, record a mean of 18.319 cm. while the interplay middle from two points of S4 and 0 mg/L⁻¹ of proline surrendered hostile interplay mean of 11.999 cm.

Table (6) Impact of water-stress, proline concentration, and their interaction on disc diameter

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	15.841	16.319	17.429	18.319	16.977
S2	14.249	15.881	17.319	17.979	16.357
S3	12.538	13.541	16.008	16.529	14.654
S4	11.999	12.829	12.128	13.128	12.521
Average	13.656	14.642	15.731	16.488	
LSD (0.05)	Water-stress levels= 0.629 Proline concentration = 0.487 Interaction = 0.263				

Fertilization %

The measurements shown significant distinctness concerning water-stress factors and proline concentrations in implantation characteristic; still, the interaction middle from two point's determinants demonstrated no significant dissimilarities (Table 7). The remarks demonstrated that water-stress unfavorably influence the pregnancy %, as the rate declined accompanying growing stress. Factors S1, S2, and S3 created the highest advantage productivity %, and did not disagree considerably between them, accompanying mean principles of 90.96, 90.61, and 88.79%, individually. In contrast, Factor of S4 yielded the minimum mean of potency of 83.27%. This concede possibility be related to the coexistence of water-stress accompanying extreme temperatures all along impregnation of the ovum and implantation, leading to the failure of ovaries and embryos (He *et al.*, 2024). Furthermore, the observations illustrated that proline efficiently donated to increasing the virility allotment. Proline at 60, 40, and 20 mg/L⁻¹ was written the significantly taller advantage than the

control with mean principles of 90.43, 89.99, and 89.74 %, individually, and no important difference with ruling class. Meanwhile, the control situation at 0 mg/L⁻¹ yielded rude advantage, with an average of 84.36%. These remarks emphasize the benefit of proline at differing concentrations in enhancing pregnancy; proper allure role in providing children sits with quickly feasible minerals, boosting irritant endeavor, and abridgment the fertilization ending (Carvalho *et al.*, 2018).

Table (7) Impact of water-stress, proline concentrations, and their interactions on fertility%

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	85.79	92.51	92.72	92.82	90.96
S2	85.64	91.51	92.53	92.74	90.61
S3	84.61	89.19	90.62	90.75	88.79
S4	81.41	82.19	84.08	85.41	83.27
Average	84.36	89.74	89.99	90.43	
LSD (0.05)	Water-stress levels= 3.22 Proline concentration = 3.61 Interaction = N.S				

Seeds Number per Disc

The values presented in Table (8) observed important dissimilarities concerning water-stress determinant, proline concentrations, and their interaction on the number of children in discs. The verdicts shown that the determinant of water-stress (S1) recorded a considerably taller profit than the remainder of something of this characteristic, accompanying mean (640.92 beginning/disc), and acted not clash considerably from the determinant S2, with mean (633.10 source/plate) while the minimum mean was written at determinant S4, with mean (476.43 children/plate). This answer may become functional water-stress diminished the pollination rate (Table 7), through reducing the children formatted (Mostafa and Afify, 2022). The table 8 dossier manifested the influence of proline in enhancing the beginning number characteristic; proline at 60 and 40 mg/L⁻¹ created the best value and acted not clash considerably between bureaucracy, surrendered method of 690.01 and 675.63 children/ disc, individually. In contrast, the control situation at 0 mg/L⁻¹ granted the minimum mean for children of (432.94 seed/plate). It assigns to proline alive act in improving the plants water and corporeal rank, through enhancing the combination and switch of assimilates to the plate and children sites. This led to an increase in plate width and breeding rate (Tables 6 and 7), that positively affected characteristic (Van der Westhuizen, 2019). Additionally, the interplay factors of each S2 accompanying proline at 60 and 40 mg/L⁻¹ revealed important advantage in seed number, accompanying no important distinctness middle from two points them, while the interplay of S4 determinant accompanying 0 mg/L⁻¹ allowed the minimum mean of (388.58 seed/plate).

Table (8) Impact of water-stress, proline concentrations, and their interactions on seeds number per disc

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	463.19	542.19	776.66	781.62	640.92
S2	458.60	532.08	763.41	778.30	633.10
S3	421.38	468.89	620.19	636.49	536.74
S4	388.58	411.28	542.24	563.62	476.43
Average	432.94	488.61	675.63	690.01	
LSD (0.05)	Water-stress levels= 32.85 Proline concentration = 27.80 Interaction = 13.64				

100-Seed Weight

The results showed a significant effect of the two factors, while their interplay revealed no meaningful affect the pressure of 100 seeds (Table 9). The dossier written that determinant S3 was written a considerably taller value than the added determinants, accompanying mean of 7.45 g, and acted not clash significantly distinguished to determinant S2 and S1.

Conversely, the minimum mean was written on determinant (S4), at 6.65 g. The increase noticed in factor S3 can be accredit the standard of seed rectification; physiologically, this standard dictates that an increase or decrease in one yield component is with the order reversed equalized by a matching decrease or increase in added yield parts ([Ali et al., 2024](#)). Furthermore, the remarks pointed out that the proline determinant at 60 mg/L⁻¹ written a considerably higher profit than the added determinants, accompanying mean of 7.18 g, and more demonstrated a significant distinctness from the 40 mg/L⁻¹ determinant, while the control situation at 0 mg/L⁻¹ allowed the minimum mean (6.84 g). This consequence id due to the active offering of proline in claiming intracellular osmotic balance, that promoted and enhanced transport processes middle from two points the beginning (fertile parts) and the fall (grains), through thereby reconstructing seed pressure ([Zamani et al., 2020](#)).

Table (9) Impact of water-stress, proline concentrations, and their interactions on 100-seed weight

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	7.08	7.53	7.39	7.20	7.30
S2	7.9	7.53	7.50	7.32	7.36
S3	7.10	7.62	7.66	7.40	7.45
S4	6.08	6.78	6.97	6.78	6.65
Average	6.84	7.37	7.38	7.18	
LSD (0.05)	Water-stress levels= 0.20 Proline concentration = 0.11 Interaction = N.S				

Seed Yield

The findings determined important difference middle from two points the 2-determinants and their interplays concerning seed yield (Table 10). The got dossier designated that the S1 stress-determinant recorded a considerably taller worth than the additional factors in this place characteristic, accompanying mean of 3.76 t ha⁻¹, but no important difference accompanying the S2 determinant at 3.66 t ha⁻¹, while the S4 stress-determinant shown the minimum mean of 2.25 t ha⁻¹. The decline on seed yield of S4 determinant was from water-stress creating a decline in yield elements, thereby in another way moving the ending yield came from these components (Table 8 and 9), in addition to lowering potency rates (table 7), that lowered the ending yield abundance ([Chauke, 2024](#)). Furthermore, the dossier showed that the proline determinant at 60 and 40 mg/L⁻¹ recorded a considerably taller profit than the different factors (accompanying no important dissimilarity betwixt them), flexible method of 3.70 and 3.59 t ha⁻¹ individually. In contrast, the proline determinant at 0 mg/L⁻¹ (control) resulted in mean of 2.52 t ha⁻¹. These notes emphasize the act and adeptness of proline in enhancing yield elements that definitely jolted the last yield ([Al-Zubaidi and Awaid, 2023](#)). The interaction more had meaningful effect; the interplay of each determinants (S1 + 60 mg/L⁻¹ of proline) produced the maximal worth, accompanying mean of 4.12 t ha⁻¹, but acted not differ considerably accompanying interplay determinants (S1+ proline at 40 mg/L⁻¹), which attained mean of 4.09 t ha⁻¹. Meanwhile, the minimum mean was noticed in the interplay determinants (S4+ proline at 0 mg/L⁻¹), with mean of 1.61 t ha⁻¹.

Table (10) Impact of water-stress, proline concentrations, and their interaction on seed yield

Water-stress level	Proline Concentration (mg/L ⁻¹)				Average
	0	20	40	60	
S1	3.21	3.63	4.09	4.12	3.76
S2	3.17	3.49	3.98	4.01	3.66
S3	2.08	2.29	3.70	3.81	2.97
S4	1.61	1.97	2.59	2.84	2.25
Average	2.52	2.85	3.59	3.70	
LSD (0.05)	Water-stress levels= 0.23 Proline concentration = 0.14 Interaction = 0.04				

CONCLUSIONS

The present work illustrated the significance and productiveness of proline as an osmo-protectant in mitigating the damage due to water inadequacy and improving water use effectiveness, particularly by reducing watering-water use by 25%. This reveals new potential for extending the terrestrial range and cultivation of sunflower in middle of restricted water chance. Furthermore, growing proline levels surpassed to betterings in all studies calculated traits all, with pushing overall yield; in essence, it together improved water use effectiveness and raised the last crop yield.

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