Effect of site, irrigation methods and selenium spraying on some flower morphology parameters and yield of sunflower (Helianthus annuu L(.

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Abstract
A field experiment was performed in the spring and autumn agricultural seasons of 2023 in two distinct locations within Dhi Qar Governorate. The initial site is situated within the agricultural fields of the Al-Rifai District, 85 km north of Dhi Qar Governorate, at a latitude of 36°44'310" N and a longitude of 08°07'460" E. This area is distinguished by its sandy mixed soil and is irrigated by the small Sabila River, which branches from the Al-Gharraf River. The second site is situated in the Al-Shatr District of Bani Zaid, specifically for the Organic Fertilizer Preparation Project, located 70 km northeast of Dhi Qar Governorate at latitude 20° 130.24' N and longitude 07° 460.17' E. This area is distinguished by its clayey mixed soil and receives irrigation from the Al-Gharraf River. The research encompassed two experimental sites between Al-Rifai P1 and Al-Shatra P2 regions, examining three irrigation techniques: flood irrigation (W1), above-surface drip irrigation (W2), and below-surface drip irrigation (W3). Application of five levels of nano-selenium and conventional selenium (S0,S1,S2,S3,S4) at concentrations of 0, 5, 10, and 15 mg of nano-selenium and 50 mg of traditional selenium on the growth and yield of sunflower. The experiment employed a split-plot methodology within a randomized complete block design (RCBD). The primary plots featured irrigation techniques, whilst the selenium spray concentrations constituted the sub-plots. The study demonstrated the superiority of the nano-selenium spray concentration S3 (15 mg L-1) across all levels and averages for the examined features, specifically the number of leaves, which were 28.3 and 26.7 leaves. Leaf area, 6917.3 cm², and certain features (leaf area, 4961.4 cm²) surpassed the sequence for the autumn season. The flood irrigation method (W1) demonstrated superior performance in growth, yield, and leaf area traits, achieving 6434.8 cm² during the spring season. Additionally, in the fall season, flood irrigation (W1) excelled in leaf area traits with a measurement of 4946.9 cm², attributed to a significant interaction between the site and irrigation methods. Notably, the subsurface drip irrigation treatment at the second site, Al-Shatra (P2×W3), exhibited superiority in the number of leaves, recording 27.6 leaves in the spring season, as well as in leaf area, measuring 4986.2 cm² in the fall season. The initial site exhibited markedly enhanced interaction with the flood irrigation method for the attribute of leaf area, measuring 6650 cm² throughout the spring season. The Al-Shatra site demonstrated substantial superiority in the flood irrigation method W1 with selenium spraying for some features, including a leaf area of 7554.9 cm² during the spring season.
Keywords: irrigation, selenium, yield, sunflower

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Introduction:

The sunflower, scientifically designated as Helianthus annuus L., is a member of the Asteraceae family and is considered a strategic crop owing to its diverse use. It necessitates contemporary irrigation techniques that function with low flow, localized wetting, and frequent application. In comparison to conventional watering techniques, drip irrigation systems function with enhanced efficiency and superior production metrics [1]. Nanotechnology has progressed significantly in various domains, particularly in agriculture, where it pertains to nanofertilizers and agricultural chemistry aimed at promoting sustainable practices. Nanofertilizers enhance plant growth and yield by efficiently supplying nutrients in alignment with the crop growth curve. Their superior capacity to infiltrate, transport, and directly interact with plant cells via sieve elements in the cell wall is attributed to the nanoparticle dimensions, which are smaller than the cell wall pore sizes (5-20 nm). This characteristic significantly indicates improved plant utilization and absorption, thereby advancing agricultural practices [2]. Selenium is a vital mineral that significantly contributes to the health of humans and animals. Selenium is an essential component of enzymes required for bodily functions and acts as an antioxidant. Inadequate dietary selenium can lead to health issues, including compromised immune function, thyroid dysfunction, and potential associations with certain diseases. Consequently, it is advisable to consume foods rich in selenium, including fish, meat, nuts, and whole grains. Consuming fewer than 40 micrograms per day may result in malnutrition. Doses over 400 micrograms per day will be lethal for people. Consequently, its shortage has resulted in oxidative metabolic illnesses, including cancer, cardiovascular diseases, diabetes, infertility, and compromised immunological function [3.[

Materials and methods

Experiment site:A field experiment was executed in Dhi Qar Governorate during the spring and autumn agricultural seasons of 2023 AD at two distinct sites characterized by varying soil, water, and environmental conditions: one in Al-Rifai District and the other in Al-Shatrah District - Bani Zaid. The research is to examine the impact of irrigation techniques and selenium spray concentrations on the growth, yield, and quality of sunflowers. Soil samples were collected randomly from both sites at a depth of 0-30 cm before to planting, thereafter blended to achieve homogeneity, air-dried, and smoothed with a plastic hammer for each site individually. A sieve with 2 mm diameter apertures was employed to filter the soil. Certain chemical and physical qualities were assessed in the laboratory of the Department of Soil Sciences and Water Resources at the College of Agriculture, Al-Muthanna University.

Study factors: The experiment included three study factors:

First factor: - The two sites of the experiment, symbolized by the letter P.

First site: The experiment was carried out in one of the agricultural fields located in Al-Rifai district, 90 km north of Dhi Qar Governorate, located at latitude 36 44 310 north and longitude 08 07 460 east, symbolized by the letter P1.

Second site: In Al-Shatrah district - Bani Zaid sub-district - Organic fertilizer preparation project, 80 km northeast of Dhi Qar Governorate, located at latitude 20 24 310

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north and longitude 07 17 460 east, symbolized by the letter P2.

Second factor: Three irrigation methods, symbolized by the letter W.

-1Flood irrigation, symbolized by the letter W1.

-2Above-surface drip irrigation, symbolized by the letter W2.

-3Subsurface drip irrigation, symbolized by the letter W3.

The third factor: five levels of spraying, which are: - Spraying with the element selenium, symbolized by the letter S and manufactured by the American company Nanoshell, Table No. (3) includes five levels as shown below.

-1Spraying with distilled water for the comparison treatment ((S0.

-2Spraying with nano selenium 5 mg L-1 (S1.(

-3Spraying with nano selenium 10 mg L-1 (S2.(

-4Spraying with nano selenium 15 mg L-1 (S3.(

-5Spraying with traditional selenium 50 mg L-1 (S4.(

The investigation utilized a factorial design strategy across both sites (Al-Rifai - Al-Shatra), employing a randomized complete block design (R.C.B.D) inside a plot and comprising three replicates [3]. The experiment had 90 experimental units, with 45 allocated to each site (3×5×3) on a plot that encompassed all combinations of the researched parameters and their repeats. Irrigation methods constitute the primary plots, while various selenium spray combinations serve as the sub-plots. Agricultural operations: Following the selection of two suitable agricultural sites for the research, plowing was conducted perpendicularly with a rotary plough, subsequently followed by smoothing and leveling using disc harrows and a leveling machine. Urea fertilizer (N 46%) served as a nitrogen source, triple superphosphate fertilizer (P2O5 46%) as a phosphorus source, and potassium sulfate (K2O 50%) as a potassium source. Phosphate and potassium fertilizers were incorporated into the soil prior to planting in a single application, following a recommendation of 160 kg N ha-1, 100 kg P2O5 ha-1, and 160 kg K2O ha-1 [5], and well mixed using a rotary plow. The nitrogen fertilizer was applied in two increments. The initial batch was introduced four weeks post-seedling emergence, and the subsequent addition occurred two weeks following the first fertilization. The fertilizer was applied as a supplement for the irrigation treatments in accordance with the fertilizer guidelines. The drip irrigation system was integrated with irrigation water through the drip method after thorough dissolution in the irrigation water [6]. Each site was partitioned into three equal sectors, with a distance of 2 meters separating each sector. Each sector was further subdivided into 15 experimental units, each with an area of 7.5 m² (2.5 x 3 m), and the distance between each experimental unit was 0.5 meters. The experimental unit comprised four lines, with a spacing of 75 cm between each line and 25 cm between individual plants. The cultivation was conducted in rows to attain a plant density of 53,333 plants per hectare. Each section was randomly allocated one of three irrigation methods. The initial method involved five experimental units of flood irrigation, while the subsequent method utilized above-surface drip irrigation through a GR pipe drip irrigation system. The interval between each dripper was 25 cm, while the third technique employed was subterranean watering. The pipes were installed underground at a depth of 20 cm [7]; [8]. The calibration irrigation was implemented and maintained until the requisite dryness was achieved for the planting phase. The hybrid sunflower seeds (Lilo) were sown for the spring season on February 16, 2023, and for the autumn season on July 1, 2023, at both sites, at a depth of 3 cm and at a density of three seeds per hole. The pruning of the plants to a single specimen per hole was executed two weeks following the emergence of the seedlings. Weeding was conducted manually as required. Six weeks post-planting, selenium was applied as per the specifications in Table No. (2) during the early morning, utilizing quantities of 5, 10, and 15 mg of nano selenium and 50 mg of conventional selenium per liter of water for the initial application. The spraying procedure was conducted again two weeks post-initial application at a rate of 400 liters per hectare, corresponding to the selenium fertilizer quantities applied as foliar sprays (0.04, 0.008, 0.012, 0.004, 0 kg Se per hectare) for treatments S4, S3, S2, S1, and S0, respectively. Once the nettles reached full maturity and were laden with seeds, they were covered with netting to prevent avian damage. Harvesting commenced for the first site on June 14, 2023, and for the second site on June 16, 2023, during the spring season, while the autumn harvest occurred on October 20, 2023, for both sites.

Table (1) shows the concentrations of nano-selenium and conventional selenium sprays and the amounts of addition in kg ha-1.

Fertilizer source	**nano**	**nano**	**nano**	**nano**	**conventional**
Selenium treatments	**S0**	**S1**	**S2**	**S3**	**S4**
Concentrations mg Se L-1	**0**	**5**	**10**	**15**	**50**
Addition amount kg Se H-1	**0**	**0.004**	**0.008**	**0.012**	**0.04**

Preparation of nano and conventional selenium solutions involved the formulation of four concentrations, three of which were nano and one conventional (0, 5, 10, 15, and 50 mg L-1). Pure distilled water was utilized, and Tween 20 was incorporated as a surfactant to diminish surface tension. The solutions were applied to the plant leaves in the early morning with a 15-liter shoulder-mounted sprayer until thoroughly saturated, six weeks post-germination, with a subsequent application occurring two weeks after the initial spray for each season and research site.

Table (2) shows the selenium used in preparing the solution

Element	**Manufacturing Company**	Element ratio	Shape and color	Molecular weight	Density	Melting point	**Boiling point**
Nano Selenium	**Nanoshell USA**	99.9% nm	Grey black powder	78.96 g mol-1	81:4 g/cm-3	217°C	**684.9 °C**
Conventional Selenium	**BDH Paul England**	**99.5% Assay Selenium Powder**	Light black powder	78.96 g mol-1	**----**	**----**	**----**

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Overview and installation of the irrigation system: The experiment involved three irrigation methods: flood irrigation, characterized by the extensive use of water; surface drip irrigation; and subsurface drip irrigation. An irrigation system utilizing pipes specifically for surface drip irrigation was employed, while subsurface drip irrigation utilized 2-inch polyethylene main pipes and 16 mm Uni-Pc cylindrical secondary pipes, which contained drippers integrated within the inner wall of the drip pipes, functioning based on the principle of water flow under low pressure conditions. The experimental units for each treatment in the open system featured both surface and subsurface drip irrigation systems, with a plastic plug installed at the end of each line to facilitate cleaning and enhance irrigation efficiency [9]. The irrigation system comprises the following fundamental components.

.1 2inch water pump (submersible) placed inside a plastic clip and covered from the outside with a transparent tube to prevent the entry of impurities and foreign objects.

.2 2inch polyethylene plastic pipe, 150 meters long, to transfer water from the river to the tank.

.3 5000liter water tank, installed at a height of one meter above the field level for the purpose of water flow under low pressure.

.4 2inch main polyethylene plastic pipe to transfer irrigation water from the tank to the field, connected to the tank and a key at the beginning and a plug at the end.

.5 2inch branch polyethylene plastic pipes, tightly connected to the main pipe by a 2 inch key to transfer irrigation water inside the field.

.6 16mm plastic pipes containing drippers, the distance between one dripper and the next is 25 cm, to transfer irrigation water to the plants inside the experimental units.

Measurements of drip irrigation system standards: The dripper discharge was calculated using the following equation proposed by[10:[

$$q = \frac{V}{t}$$

q: Drip discharge (liters, hour-1(

V: Volume of water flowing from the dripper (liters (

t: Operating time (hours(

The average drip discharge was calculated using the following equation proposed by [11[

$$q = \frac{q1 + q2 + q3 + q4 \ldots\ldots\ldots\ldots qn}{n}$$

Average dripper discharge (l.h-1):q

Dripper discharge (l.h-1):q1 + q2 + q3

Number of drippers:n

Water consumption of sunflower crop: Sunflower crop is a summer crop, which grows between 8 - 30 °C without reducing its production quantity, but it grows quickly between 15 - 30 °C. In the advanced stages of the plant's life, it needs a warm atmosphere. Its planting date is the beginning of March and the maturity date is in June for the spring season, while for the autumn season. Knowing the water consumption is the first step in calculating the water requirements of different agricultural crops. Water consumption of sunflower crop was calculated for previous studies based on the calculated potential evaporation and transpiration amounts using the Penman-Monteith method, according to the following equation: ETc = ETo × Kc

Where:

ETc: Crop evaporation-transpiration (water consumption(

ETo: Potential evaporation-transpiration

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Kc: Crop growth factor

The value of the crop coefficient Kc was measured for each stage of its growth from previous field experiments and these values were recorded in tables previously published by the Food and Agriculture Organization of the United Nations [12[

How to calculate the water quotient (total water requirement): The water quotient for the sunflower crop can be calculated from the following equation: FIR=ET/Ei Where: FIR = water quotient, ET = water consumption, Ei = irrigation efficiency.

Table (3) Water ration and irrigation method efficiency for the two seasons of sunflower crop.

Irrigation method	Flood irrigation	Surface drip irrigation	Subsurface drip irrigation
Method efficiency	%65	%90	%95

Water consumption ET for sunflower crop in Dhi Qar Governorate for the spring season 1002 mm and for the autumn season 1280 mm

Table (4) Water quota (mm) for sunflower crop for the spring and autumn seasons

Season	Water consumption mm	Water level mm		
		Flood irrigation	Surface drip irrigation	Subsurface drip irrigation
Spring	1002	1541.5	1113.3	1054.7
Autumn	1280	1969.2	1422.2	1347.4

Table (5) Water quota (m3 h-1) for sunflower crops for the spring and autumn seasons

Season	Water consumption mm	Standard M3		
		Flood irrigation	Surface drip irrigation	Subsurface drip irrigation
Spring	1002	15415	11133	10547
Autumn	1280	19692	14222	13474

Water Use Efficiency (WUE) (kg yield per cubic meter of water) Water use efficiency was determined using the following equation [13]: Water use efficiency = production quantity (kg h^{-1}) for any treatment / quantity of water added (m^3.(

The examined attributes :

The number of leaves per plant is determined by counting the total leaves from the first green leaf to the last leaf in the two central lines of the experimental unit.

The leaf area (m^2) of the plant was determined using the formula provided by [14] the sum of the squares of the widths of the leaves from the sixth roll multiplied by 4.31 .

Yield indicators and components: The plants from the two central rows of each experimental unit were individually harvested at full maturity. Subsequently, the discs were manually separated, and the seeds were air-dried for each disc individually. An analysis of the yield and its components was performed on them, including

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The average number of seeds in the disc (seed disc-1) was determined after manual separation.

The individual plant yield (g plant-1) was determined by measuring the seed yield weight of ten plants selected from the two central rows, from which the yield per each plant was calculated.

Total seed yield (megagrams ha-1) is determined by measuring the seed yield of the two central rows, calculating the area of these rows at a moisture content of 8%, and subsequently converting the total output to tons per hectare .

Fertilization rate (%): A random sample of 50% of the seeds was taken for each experimental unit, according to the number of empty and full seeds. Then the fertilization rate was calculated according to the above equation :

Fertility rate = Number of seeds filled / Number of empty seeds + Number of filled seeds*100 [15[

Statistical analysis: The field experiment was conducted using a randomized complete block design and a nested design arrangement, incorporating the primary factor of sites (Shatra and Al-Rafai). The RCBD design was employed at both sites, utilizing a split-panel arrangement. The primary factor consisted of various irrigation methods (flood, above-surface drip irrigation, and below-surface drip irrigation), while the secondary panels encompassed different levels of selenium application (spraying with distilled water, nano-selenium at 5 mg.L-1, nano-selenium at 10 mg.L-1, nano-selenium at 15 mg.L-1, and traditional selenium at 50 mg.L-1). The analysis was conducted in accordance with the variance analysis table provided below (7). The means were analyzed using the LSD test at a significance level of 5%. The analysis was conducted utilizing Genstat V. 12.1 software.

Results and discussion

Number of leaves (leaf plant-1(

The results presented in Tables 5 and 6 indicated notable differences in the impact of selenium concentration spraying levels across the two seasons. Treatment S3 yielded the highest average, with 28.3 and 26.7 leaves per plant, respectively, whereas treatment S0 recorded the lowest average, with 24.9 and 20.5 leaves per plant, respectively. The augmentation in leaf quantity of the plant following the application of selenium spray may be attributed to the element's significant capacity to enhance the availability of nutrients for the plant. This, in turn, influences the increase in plant height, which is a consequence of the number of internodes and other vegetative growth characteristics, due to its beneficial impact on essential physiological processes, particularly regulatory and stimulatory functions. This effect is manifested in the preparation of new growth sites within the plant, fulfilling their growth requirements, thereby resulting in an increase in leaf count [16]. The results from the table indicate that there are no significant differences in the average irrigation methods between the two seasons at the sites (Al-Rifai and Al-Shatra), nor in the binary interaction between them. Additionally, there are no significant differences in the triple interaction involving the site, irrigation methods, and the application of nano-selenium and traditional spraying concentrations. The findings from the two tables indicated a binary interaction and a significant enhancement between irrigation methods and selenium spraying for this trait. The treatment (S3×W3) yielded the highest averages of 29.1 and 27.1 leaves per plant for the two seasons, respectively, in contrast to

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treatment (S0×W3), which produced the lowest averages of 24.5 and 20 leaves per plant for the same seasons, respectively. The augmentation in leaf quantity may be ascribed to the elevation in plant height; specifically, a taller plant correlates with a greater number of leaves. These findings align with those of [17], [18], The interaction between sites and spray concentrations reveals a significant increase in leaf count when utilizing selenium concentrations across different sites. Specifically, treatment (S3×P2) yielded the highest averages of 29.5 and 27 leaves per plant, respectively, in contrast to treatment (P2×S0), which produced the lowest averages of 24.4 and 19.6 leaves per plant, respectively, across both seasons. This increase in leaf quantity may be attributed to the application of nano-selenium spray at a concentration of 15 mg per nanoliter. This may explain the susceptibility of this element to enhance the availability of other elements and nutrients for plants, thereby delaying the traits of vegetative growth through its beneficial impact on essential processes, which facilitates the conditions for new plant emergence in their growth requirements, resulting in an increase in the number of leaves in the plants. This outcome aligns with the findings of [19.[

Table (6) The effect of the site, irrigation methods and spraying with nano-selenium levels and the interaction between them in the number of leaves - spring season

site (P)	Irrigation Methods (W)	Selenium (S) (mg L-1)					P * W	
		S0	S1	S2	S3	S4		
P1	Spate Irrigation	24.8	24.5	28.4	26.2	28.9	26.6	
	Surface Drip Irrigation	26.9	28.5	25.9	26.8	26.6	26.9	
	Subsurface Drip Irrigation	24.8	26.6	25.8	28.5	28.3	26.8	
P2	Spate Irrigation	24.2	26.7	26.4	29.8	28.7	27.2	
	Surface Drip Irrigation	24.8	28.3	28.2	28.9	26.1	27.3	
	Subsurface Drip Irrigation	24.2	27.0	28.9	29.8	28.3	27.6	
LSD P*W*S		N.S					LSD P*W	N.S
P * S								
Site		S0	S1	S2	S3	S4	Average site	
P1		25.5	26.5	26.7	27.2	27.9	26.8	
P2		24.4	27.3	27.8	29.5	27.7	27.4	
LSD P*S		2.21					LSD P	N.S
W * S								
Irrigation Methods		S0	S1	S2	S3	S4	Average irrigation methods	
Flood Irrigation		24.5	25.6	27.4	28.0	28.8	26.9	
Suprasurface Drip Irrigation		25.8	28.4	27.0	27.9	26.4	27.1	
Subsurface Drip Irrigation		24.5	26.8	27.4	29.1	28.3	27.2	
LSD W*S		1.60					LSD W	N.S

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S					
Selenium	S0	S1	S2	S3	S4
Medium Selenium	24.9	26.9	27.3	28.3	27.8
LSD S	0.96				

Table (7) Effect of site, irrigation methods, spraying with nano-selenium levels and their interaction on the number of leaves - autumn season

site (P)	Irrigation Methods (W)	Selenium (S) (mg L-1)					P * W	
		S0	S1	S2	S3	S4		
P1	Spate Irrigation	21.4	22.8	25.6	25.6	25.2	24.1	
	Surface Drip Irrigation	21.6	24.8	23.6	26.1	24.7	24.2	
	Subsurface Drip Irrigation	20.8	23.3	27.2	27.1	24.1	24.5	
P2	Spate Irrigation	19.5	23.4	23.0	26.8	25.6	23.7	
	Surface Drip Irrigation	20.1	24.5	23.6	27.2	22.5	23.6	
	Subsurface Drip Irrigation	19.3	24.0	24.0	27.1	24.5	23.8	
LSD P*W*S		N.S					LSD P*W	N.S
P * S								
Site		S0	S1	S2	S3	S4	Average site	
P1		21.3	23.6	25.5	26.3	24.6	24.3	
P2		19.6	24.0	23.5	27.0	24.2	23.7	
LSD P*S		2.04					LSD P	N.S
W * S								
Irrigation Methods		S0	S1	S2	S3	S4	Average irrigation methods	
Flood Irrigation		20.5	23.1	24.3	26.2	25.4	23.9	
Suprasurface Drip Irrigation		20.9	24.6	23.6	26.7	23.6	23.9	
Subsurface Drip Irrigation		20.0	23.6	25.6	27.1	24.3	24.1	
LSD W*S		1.34					LSD W	N.S
S								
Selenium		S0	S1	S2	S3	S4		
Medium Selenium		20.5	23.8	24.5	26.7	24.4		
LSD S		0.83						

Leaf area (cm2(

The results presented in Tables 7 and 8 indicate a substantial enhancement in the leaf area of the plant due to varying spray levels of nano and conventional selenium concentrations. Treatment S3 yielded the highest average for this trait, measuring 6917.3 cm² and 5895 cm² for the two seasons, respectively, in contrast to treatment S0, which recorded the lowest average at 5373.7 cm² and 3608.6 cm², respectively. The results from the table indicate a substantial enhancement in the irrigation method

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treatments for this trait. Specifically, treatment (W1) yielded the highest averages of (6434.8 and 4946.9) cm² for the two seasons, respectively. Conversely, treatment (W3) in the spring season and treatment (W2) in the autumn season recorded the lowest averages of (5605.3 and 4681) cm², respectively. This is related to the climatic conditions at each stage of plant growth and their effect on seasonal water consumption (Table 6). The plant's seasonal water consumption escalates with the duration of the growth cycle across all irrigation settings, peaking during the vegetative development stage. This is attributable to the heightened water requirements of the plant during a critical phase of growth, physiological development, and root expansion, which enhances their efficiency in water absorption and consequently increases leaf area. Moreover, an increase in leaf area enhances water loss from the plant via transpiration, compounded by elevated temperatures and solar radiation intensity during the day. This signifies heightened water losses due to increased evaporation from the soil surface, thereby augmenting the crop's water requirements, as illustrated in Table (5). This aligns with [20]. The data presented in the table reveal that there is no notable increase during the spring season; however, substantial differences are observed in the fall season, with treatment (P2) yielding the highest average of (4961.4) cm², in contrast to treatment (P1), which recorded the lowest average of (4605.9) cm² for the leaf area characteristic .

The findings reveal a notable interaction between irrigation methods and sites (Al-Rifai and Al-Shatra), with treatment (W1×P1) in the spring and treatment (P2×W3) in the fall yielding the highest averages of (6650 and 4986.2) cm², respectively, in contrast to treatment (P1×W2), which produced the lowest averages of (5533 and 4399.3) cm² for both seasons.

The interaction between irrigation methods and selenium concentrations yielded significant results, as indicated in the two tables. The treatment (S3×W1) in spring and (S3×W3) in fall produced the highest averages of 7247.7 cm² and 5963.7 cm², respectively, while the treatment (S0×W3) in spring and (S0×W2) in fall resulted in the lowest averages of 5189.7 cm² and 3318.8 cm². A notable interaction exists between the site and the application of nano-selenium and traditional spraying, as the treatment (P2×S3) attained the highest measurements of (7483.1 and 6487.7) cm2 for the two seasons, respectively, in contrast to the treatment (P2×S0) in the spring season and the treatment (P1×S0) in the autumn season, which yielded the lowest measurements of (5236.3 and 3456.8) cm2. The data in the table indicated a significant effect of the triple interaction, with the treatment (P2×W1×S3) in the spring season and the treatment (P2×W2×S3) in the autumn season yielding the highest average leaf area, measuring 7554.9 and 6584.6 cm², respectively. In contrast, the interaction treatment (S0×P2×W1) in the spring season and the treatment (P1,W2,S0) in the autumn season produced the lowest averages, measuring 4793.2 and 3124.9 cm², respectively, for both seasons. The augmentation of leaf area may result from adequate moisture levels in the root zone, alongside enhanced nutrient availability and accessible water, as well as exposure to sunlight. This aligns with the findings of [21] who observed that leaf area and its index in sunflowers diminished with reduced water quantities and the consequent effects of water stress.

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Table (8) Effect of site, irrigation methods, spraying with nano-selenium levels and their interaction on leaf area - spring season

site (P)	Irrigation Methods (W)	Selenium (S) (mg L-1)					P * W	
		S0	S1	S2	S3	S4		
P1	Spate Irrigation	5868.4	7388.0	6649.1	6940.5	6404.1	6650.0	
	Surface Drip Irrigation	5693.1	5446.0	5213.6	5748.2	5564.3	5533.0	
	Subsurface Drip Irrigation	4971.9	5846.8	5343.8	6365.7	5736.1	5652.8	
P2	Spate Irrigation	4793.2	5975.4	6352.7	7554.9	6421.3	6219.5	
	Surface Drip Irrigation	5508.0	6951.2	7040.6	7455.2	5814.7	6553.9	
	Subsurface Drip Irrigation	5407.6	6532.8	6868.5	7439.1	5474.5	6344.5	
LSD $_{P*W*S}$		533.60					LSD $_{P*W}$	463.33
P * S								
Site		S0	S1	S2	S3	S4	Average site	
P1		5511.1	6227.0	5735.5	6351.5	5901.5	5945.3	
P2		5236.3	6486.5	6753.9	7483.1	5903.5	6372.7	
LSD $_{P*S}$		465.33					LSD $_P$	N.S
W * S								
Irrigation Methods		S0	S1	S2	S3	S4	Average irrigation methods	
Flood Irrigation		5330.8	6681.7	6500.9	7247.7	6412.7	6434.8	
Suprasurface Drip Irrigation		5600.6	6198.6	6127.1	6601.7	5689.5	6043.5	
Subsurface Drip Irrigation		5189.7	6189.8	6106.2	6902.4	5605.3	5998.7	
LSD $_{W*S}$		275.09					LSD $_W$	135.23
S								
Selenium		S0	S1	S2	S3	S4		
Medium Selenium		5373.7	6356.7	6244.7	6917.3	5902.5		
LSD $_S$		161.10						

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Table (9) Effect of site, irrigation methods, and spraying on nano-selenium levels and their interaction on leaf area – autumn season

site (P)	Irrigation Methods (W)	Selenium (S) (mg L-1)					P * W	
		S0	S1	S2	S3	S4		
P1	Spate Irrigation	3780.7	4412.0	5627.3	5430.5	5544.4	4959.0	
	Surface Drip Irrigation	3124.9	4082.7	5618.1	5084.2	4086.8	4399.3	
	Subsurface Drip Irrigation	3464.8	4470.2	4433.8	5392.3	4535.4	4459.3	
P2	Spate Irrigation	3773.2	4348.8	5351.4	6343.5	4857.3	4934.8	
	Surface Drip Irrigation	3512.7	4838.5	5159.3	6584.6	4720.4	4963.1	
	Subsurface Drip Irrigation	3995.2	4117.4	5346.9	6535.1	4936.5	4986.2	
LSD P*W*S		357.03					LSD	298.49
P * S								
Site		S0	S1	S2	S3	S4	Average site	
P1		3456.8	4321.6	5226.4	5302.4	4722.2	4605.9	
P2		3760.4	4434.9	5285.8	6487.7	4838.1	4961.4	
LSD P*S		299.76					LSD P	303.16
W * S								
Irrigation Methods		S0	S1	S2	S3	S4	Average irrigation	
Flood Irrigation		3776.9	4380.4	5489.3	5887.0	5200.9	4946.9	
Suprasurface Drip Irrigation		3318.8	4460.6	5388.7	5834.4	4403.6	4681.2	
Subsurface Drip Irrigation		3730.0	4293.8	4890.4	5963.7	4735.9	4722.8	
LSD W*S		196.64					LSD W	113.32
S								
Selenium		S0	S1	S2	S3	S4		
Medium Selenium		3608.6	4378.3	5256.1	5895.0	4780.1		
LSD S		109.97						

Number of empty seeds:

The results from Tables 9 and 10 indicated significant disparities in the number of empty sunflower seeds when comparing nano and conventional selenium concentrations. The control treatment S0 recorded the highest values for this trait, reaching 314.1 and 300.9 for the two respective seasons, while treatment S3 exhibited the lowest number of empty seeds, with values of 166.2 and 146.1 for the same seasons. The cause may be ascribed to the impact of selenium spraying on the vegetative group of sunflowers. The fertility rate rose in the sprayed treatment, whereas the subsurface drip irrigation method during the

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fall season attained the highest value, with (223.8) empty seeds for flood irrigation and (220.6 and 192.4) for above-surface drip irrigation, respectively. The issue arises from the impact of drip irrigation techniques, specifically the spacing of lines at 75 cm in the experimental study, which hinders the adequate wetting of the entire root zone, consequently limiting root extension and directly affecting fertility percentages during the flowering stage. Seed size is influenced by moisture stress and genetic factors to a greater extent than environmental conditions, with exceptions. Water scarcity during seed development results in diminished seed size, thereby reducing yield, maybe due to its impact on photosynthetic rates and the hastening of leaf senescence [22]. The reduction in seed yield under inadequate water supply was attributed to a decrease in disc size (15 and 16) and seed weight, stemming from diminished photosynthetic efficiency and impaired transsite of organic matter from source to sink, corroborating the findings of [23] There are no substantial variations in the binary and triple interactions over the spring and autumn seasons.

Table (10) Effect of site, irrigation methods, spraying with nano-selenium levels and interaction on the number of empty seeds - for the spring season

site (P)	Irrigation Methods (W)	Selenium (S) (mg L-1)					P * W	
		S0	S1	S2	S3	S4		
P1	Spate Irrigation	303.3	218.0	216.3	198.0	247.3	236.6	
	Surface Drip Irrigation	278.7	218.7	235.0	158.7	244.3	227.1	
	Subsurface Drip Irrigation	364.7	226.0	211.0	187.3	252.8	248.4	
P2	Spate Irrigation	312.7	206.5	225.7	152.7	270.3	233.6	
	Surface Drip Irrigation	303.7	250.0	230.0	158.0	232.3	234.8	
	Subsurface Drip Irrigation	321.7	229.7	252.7	142.7	208.3	231.0	
LSD P*W*S		N.S					LSD	N.S
P * S								
Site		S0	S1	S2	S3	S4	Average site	
P1		315.6	220.9	220.8	181.3	248.2	237.3	
P2		312.7	228.7	236.1	151.1	237.0	233.1	
LSD P*S		N.S					LSD P	N.S
W * S								
Irrigation Methods		S0	S1	S2	S3	S4	Average	
Flood Irrigation		308.0	212.2	221.0	175.3	258.8	235.1	
Suprasurface Drip Irrigation		291.2	234.3	232.5	158.3	238.3	230.9	

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Subsurface Drip Irrigation	**343.2**	**227.8**	**231.8**	**165.0**	**230.6**	**239.7**	
LSD $_{W*S}$	**N.S**					**LSD $_{W}$**	**N.S**
S							
Selenium	**S0**	**S1**	**S2**	**S3**	**S4**		
Medium Selenium	**314.1**	**224.8**	**228.4**	**166.2**	**242.6**		
LSD $_{S}$	**32.4**						

Table (11) Effect of site, irrigation methods, spraying with selenium levels and interference on the number of empty seeds - for the fall season

site (P)	Irrigation Methods (W)	Selenium (S) (mg L-1)					P * W	
		S0	S1	S2	S3	S4		
P1	Spate Irrigation	**316.7**	**191.3**	**206.5**	**168.7**	**214.1**	**219.5**	
	Surface Drip Irrigation	**228.7**	**148.7**	**198.3**	**134.7**	**184.3**	**178.9**	
	Subsurface Drip Irrigation	**302.3**	**226.0**	**194.3**	**183.3**	**211.5**	**223.5**	
P2	Spate Irrigation	**281.3**	**238.6**	**219.0**	**146.3**	**223.7**	**221.8**	
	Surface Drip Irrigation	**305.0**	**246.7**	**153.3**	**115.3**	**209.0**	**205.9**	
	Subsurface Drip Irrigation	**371.7**	**200.3**	**223.3**	**128.0**	**197.0**	**224.1**	
LSD $_{P*W*S}$		**N.S**					**LSD**	**N.S**
P * S								
Site		**S0**	**S1**	**S2**	**S3**	**S4**	**Average site**	
P1		**282.6**	**188.7**	**199.7**	**162.2**	**203.3**	**207.3**	
P2		**319.3**	**228.5**	**198.6**	**129.9**	**209.9**	**217.2**	
LSD $_{P*S}$		**N.S**					**LSD $_{P}$**	**N.S**
W * S								
Irrigation Methods		**S0**	**S1**	**S2**	**S3**	**S4**	**Average**	
Flood Irrigation		**299.0**	**215.0**	**212.8**	**157.5**	**218.9**	**220.6**	
Suprasurface Drip Irrigation		**266.8**	**197.7**	**175.8**	**125.0**	**196.7**	**192.4**	
Subsurface Drip Irrigation		**337.0**	**213.2**	**208.8**	**155.7**	**204.2**	**223.8**	
LSD $_{W*S}$		**N.S**					**LSD $_{W}$**	**20.4**
S								
Selenium		**S0**	**S1**	**S2**	**S3**	**S4**		
Medium Selenium		**300.9**	**208.6**	**199.1**	**146.1**	**206.6**		
LSD $_{S}$		**38.9**						

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Conclusions

The individual effect of the study treatments yielded the highest averages for the majority of the examined qualities in comparison to the cumulative effect of all treatments.
The subsurface watering technique combined with nano-selenium application resulted in substantial enhancements in the majority of the examined characteristics of sunflower plants.
The subsurface drip irrigation technique, in conjunction with nano-selenium spraying at the second site, markedly enhanced the majority of the examined characteristics of sunflower plants, including several critical yield attributes .

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