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Effect of organic fertilizer and different irrigation methods on yield, fruit physical, and chemical properties of *Opuntia ficus-indica* L.

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Abstract The results on cactus pear plants revealed that sprinkler irrigation was significantly superior to other irrigation methods in terms of fruit production. Increasing manure levels significantly boosted growth, fruit yield, and quality. According to data analysis, maximum significant yield parameters were found when sprinkler irrigation was used in conjunction with sheep manure at the highest level of 30 kg/tree. This treatment resulted in a significant increase in plant height, canopy volume, number of fruits per plant, total yield per plant, juice weight per fruit, fruit T.S.S. percentage, fruit T.S.S./acid ratio, and ascorbic acid content, as well as the lowest fruit total acidity percentage.

Keywords: *Opuntia ficus-indica*, Irrigation techniques, Manure, Productivity

Introduction

Cultivating the cactus pear or Indian fig (*Opuntia ficus-indica* L., Family: Cactaceae) is common worldwide in arid and semiarid regions. The cactus pear is the most profitable harvest available for commercial purposes. The primary reason for its cultivation is the fruit. Nonetheless, it has many other uses, including cosmetics and pharmaceuticals, fodder production, and soil erosion control. Cacti are ideal crops for arid areas due to their ability to adapt to water shortages, convert water into foliage, and yield well. Fruits were traditionally used as scurvy therapy due to their high vitamin C content. Jams usually come from them. Fruits are high in healthy flavonoids. They contain glucose, fatty oil, resinous components, fructose, protein, and solids (Inglese *et al*., 2018; Abu-shama *et al*., 2022; Abou-Zaid *et al*., 2022).

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Prickly pear farming is regarded as one of Egypt's promising crops, particularly given climate change conditions. Cactus pear plantations have yet to receive the same attention in agriculture practices programs as other fruit trees that grow in Egypt's newly reclaimed expanses. The lack of agricultural information negatively impacts the yield and quality of cactus pear fruits. Cactus pear plants are physiologically and morphologically unique from almost all other crops. As a result, agronomic advice for other crops is inapplicable here. Irrigation methods and organic fertilization for cactus pear orchards are crucial, especially in newly reclaimed desert areas, and should be researched. Poor physical, chemical, and biological contents characterize these types of new soils (Akinyemi, 2007).

Even though cactus pear plants are drought-tolerant, supplementary irrigation in the summer is required for optimal output, especially in the Mediterranean geographic distribution, where most rain falls in the winter. Irrigation promotes vegetative plant growth, cladode number, and canopy size. Fruit yield per plant is higher in irrigated plants than in non-irrigated plants. Irrigation delays resulted in long-term declines in cladode number and crop. Water scarcity may harm fruit quality. Different irrigation systems, including surface irrigation, drip irrigation, and sprinkler irrigation, are utilized, and these methods determine the efficiency of the water absorbed by plants and the availability of different fertilizer types provided to the tree. Control over the quantity and quality of the resulting yield is thus possible (Paolo *et al*., 2018).

Concerning the importance of organic manure, sandy soil is poor in organic matter that requires water retention, resulting in low yields. Organic fertilizer improves the soil's physical, chemical, and biological characteristics (Akinyemi, 2007). According to Vazquez Alvarado *et al*. (2004), manure contributed to cactus pear nutrition, vegetation, and fruit output. Manure supported both systems by inducing and increasing cladodes, improving cactus pear quality, and extending the plant's productive life. Donato *et al*. (2016) stated that adding organic manure increased cladodes' maximal dry matter production. Silva *et al*. (2016) showed that increasing the organic fertilizer dose resulted in better shoot production. Based on El Gammal and Salama (2022), rising organic manure rates resulted in progressive growth enhancement, cladodes nutrient content, yield, fruit quality, net profit per feddan, and investment ratio. Lahbouki *et al*. (2022) showed that organic amendments could help reduce drought stress in prickly pear.

Recently, there has been a tendency by the Academy of Scientific Research and Technology and the Ministry of Agriculture and Land Reclamation to cultivate prickly pear on the Northwestern Coast of Egypt, where there is a shortage of irrigation water and agriculture depends on

rainwater and supplementary irrigation. The soil in these regions is calcareous and lacks nutrients and water-holding capacity. The strategy of cultivating cactus pears could increase the income of local farmers in such regions. This crop has a high economic return and a low production cost, in addition to the numerous industries that could be established on it (Mansour *et al*., 2022; Ahmed *et al*., 2023).

The goal of the current field trial was to find out how different irrigation systems, levels of organic manure, and combinations of these affect growth and the physical and chemical properties of the fruit to get the best yield on the Northwest Coast.

Materials and methods

The study was conducted for two consecutive seasons in 2021 and 2022 in El-Hammam City, Matrouh Governorate, Egypt (30° 50′ N and 29° 23′ E). The study was carried out on six-year-old cactus pear trees with a tree spacing of 2×5 m. It was taken into consideration that the plants used in the experiment were healthy and almost identical in shape, size, and yield.

The physical properties of the soil were: sand = 93.10%, silt = 1.04%, clay = 5.86%, and soil texture = sandy. The chemical analyses of the soil were as follows: pH = 8.30, organic matter = 0.10%, E.C. = 294.40 ppm, HCO_3^- = 0.02 meq/l, Cl^- = 0.05 meq/l, SO_4^{--} = 0.35 meq/l, Ca^{++} = 0.06 meq/l, Mg^{++} = 0.05 meq/l, Na^+ = 0.30 meq/l, K^+ = 0.01 meq/l, and $CaCO_3$ = 39.00%. The irrigation water's chemical properties were as follows: pH = 7.45, E.C. = 485.00 ppm, HCO_3^- = 4.83 meq/l, Cl^- = 1.73 meq/l, SO_4^{--} = 1.04 meq/l, Ca^{++} = 2.04 meq/l, Mg^{++} = 1.38 meq/l, Na^+ = 2.40 meq/l, and K^+ = 1.78 meq/l.

The experiment was conducted in a split-plot design with four replications for each treatment. The main plots involved four irrigation systems, while the subplots included four sheep manure doses. The total number of treatments was 16. The irrigation systems included drip irrigation with one drip irrigation line (lateral) for each tree row, drip irrigation with two drip irrigation lines for each tree row on each side of the tree, drip irrigation with one ring of drip tubing around the tree, and sprinkler irrigation. The subplots included the addition of four sheep manure doses of 0, 10, 20, and 30 kg/tree.

Sheep manure was added to trenches in the first week of January for both growing seasons. The manure had the following characteristics: weight of m^2 = 500 kg, organic matter = 36%, pH = 7.40, E.C. = 1640.00 ppm, N = 1.10%, C/N ratio = 16:1, P = 0.60%, K = 1.30%, Fe^{++} = 300 ppm, Mn^{++} = 130.00 ppm, Cu^{++} = 40.00 ppm, and Zn^{++} = 80.21 ppm. All agricultural practices were followed according to the recommendations of the Ministry of Agriculture and Land Reclamation, Egypt. At the time of harvest, fruits were

collected from each plant at different experimental units to evaluate the physical and chemical characteristics of the yield. The following measurements were carried out to evaluate the response of cactus pear to various treatments:

Vegetative growth indices

Tree height (m), plant canopy volume (m^3), cladodes area (cm^2), and cladodes moisture (%).

Fruiting parameters

Number of fruits/plant, yield of fruits/plant (kg), fruit weight (g), fruit length (cm), fruit diameter (cm), fruit firmness, fruit volume (cm^3), peel weight/fruit (g), pulp weight/fruit (g), juice weight/fruit (g), number of seeds/fruit, seeds weight/fruit (g), fruit T.S.S. (%), fruit total acidity content (%), fruit T.S.S./acid ratio, and ascorbic acid (mg/100 ml juice) were measured according to AOAC (1995) and Barros *et al*. (2016), the chemical tests for the fruits were determined.

The obtained data were analyzed using analysis of variance in compliance with Clarke and Kempson (1997). The 0.05 significance level was used to compare the means (Duncan, 1955).

Results

Effect of irrigation methods

Results showed the effect of different irrigation methods on growth characteristics, as shown in Tables 1 and 2. In both seasons, sprinkler irrigation recorded the highest significant values of plant height. The means of plant height were 1.74 and 1.86 m for the first and second seasons, respectively. Also, the significantly highest increments in canopy volume were caused by sprinkler irrigation. Its values for the first and second seasons were 6.72 and 7.84 m^3, respectively (Table 1). The most cladodes area were obtained under drip irrigation with rings was used. This average was 390.23 cm^2 in the first season and 369.92 cm^2 in the second season. When drip irrigation with a single lateral per tree row was used, the cladode's moisture percentage was the lowest; other irrigation techniques gave higher values, whereas differences between them were often insignificant (Table 2).

The impact of various irrigation methods on physical properties of the fruits were shown in Table 3 to 7. In both seasons, sprinkler irrigation produced

the significantly highest number of fruits per plant. These numbers were 331.88 and 310.58 fruits in the first and second seasons, respectively. Also, the significant top yield of fruits was indicated by the sprinkler irrigation. Its values were 42.92 and 39.66 kg for the first and second seasons, respectively (Table 3). The significantly highest increments of fruit weight, fruit length, and fruit diameter were obtained under ring drip irrigation. In the first season, these parameters were 126.95 g, 8.92 cm, and 4.91 cm. In the second season, these means were 125.48 g, 8.48 cm, and 4.92 cm (Table 4). When ring drip irrigation was used, the highest increases in fruit firmness, fruit volume, and peel weight were observed. These values were 12.15, 108.86 cm^3, and 57.38 g in the first season. These values were 11.66, 145.27 cm^3, and 55.57 g in the second season (Table 5). Significant top pulp weight parameters were observed under ring irrigation. In that order, these measurements were 69.57 and 69.91 g for the first and second seasons, respectively. Regarding juice weight, the best weights were obtained when ring drip irrigation and sprinkler irrigation were used; however, there were no significant differences between them (Table 6). Drip irrigation with rings produced the greatest number of seeds per fruit and seeds weight per fruit. These detections in the first season were 169.86 seeds and 10.42 g. The second season had 167.83 seeds and 11.25 g (Table 7).

The influence of different irrigation techniques on the chemical properties of the fruits was displayed in Tables 8 and 9. The top fruits' T.S.S. percentages were found when ring drip irrigation was applied in both seasons. In that order, these measures were 11.93 and 11.94 % for the first and second seasons, respectively. The highest fruit total acidity content was found when drip irrigation on one side was used. These data were 0.57 and 0.58 % in the first and second seasons, respectively (Table 8). The maximum fruit T.S.S./acid ratio was indicated by drip irrigation with rings. These estimates in the first season were 23.97 and 23.74 in the second season. Concerning ascorbic acid content in the first season, the best concentration was obtained by ring drip irrigation (15.77 mg/100 ml juice). In the second season, the superior concentrations were shown by both ring dip irrigation and sprinkler irrigation (16.28 and 16.18 mg/100 ml juice, respectively) without significant variation.

Effect of organic fertilization

It was evident that raising organic fertilizer levels significantly increased all growth and fruit production attributes. The best results were obtained by adding 30 kg of sheep manure per tree. 30 kg of manure was recorded the most increments in plant height, plant canopy volume, cladodes area, and moisture content. In the first season, these values were 1.79 m, 7.34

m^3, 434.54 cm^2, and 93.17 %. In the second season, these growth parameters were 1.87 m, 8.75 m^3, 405.22 cm^2, and 92.43 %.

Result demonstrated how increasing the rate of organic fertilizer improved the physical characteristics of fruits. The addition of sheep manure at 30 kg gave the highest increments in the number of fruits per plant, yield of fruits per plant, fruit weight, fruit length, fruit diameter, fruit volume, peel weight, pulp weight, juice weight, number of seeds per fruit, and seeds weight per fruit. In the first season, these parameters were 305.00 fruits, 38.76 kg, 123.59 g, 9.07 cm, 4.99 cm, 105.92 cm^3, 56.36 g, 67.23 g, 36.93 g, 164.80 seeds, and 10.11 g. In the second season, these means were 279.00 fruits, 36.86 kg, 129.86 g, 9.20 cm, 5.34 cm, 150.25 cm^3, 57.54 g, 72.31 g, 37.81 g, 172.16 seeds, and 11.53 g.

Increasing organic fertilizer rates also gave fruits better chemical attributes. The top rate of 30 kg showed the highest fruit T.S.S., fruit T.S.S./acid ratio, and ascorbic acid content. In the first season, these attributes were 11.50 %, 23.61, and 15.85 mg/100 ml juice. In the second season, these estimates were 11.52 %, 23.83, and 16.28 mg/100 ml juice. Contrary to the previous data, increasing organic fertilizer up to a 30 kg dose lowered the fruit's total acidity content. Its detections were 0.49 and 0.48 % for the first and second seasons, respectively.

Effect of interaction

It was evident from the results that there were significant variations in the interaction between various irrigation methods and levels of organic fertilization on the growth and fruit yield, in addition to their physical and chemical properties.

The treatment of sprinkler irrigation and applying 30 kg of sheep manure to a tree gave maximum plant height and canopy volume increments. These values in the first season were 1.93 m and 8.61 m^3; in the second season, they were 2.04 m and 9.81 m^3 (Table 1). On the other hand, the highest area of cladodes was shown under drip irrigation with rings and 30 kg/tree of manure. These values were 466.11 and 457.64 cm^2 for the first and second seasons, respectively. The highest percentage of cladodes moisture was observed under drip irrigation with rings and sprinkler irrigation with 30 kg of manure, with no significant differences (Table 2).

Table 1. Effect of irrigation methods, organic fertilization rates and, their interactions on plant height and plant canopy volume of cactus pear during the 2021 and 2022 seasons

Irrigation methods	2021					2022				
	Organic fertilizer									
	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Plant height (m)									
Single drip irrigation line	1.25 l	1.31 k	1.54 ij	1.68 f	1.44 D	1.32 o	1.39 n	1.66 j	1.74 h	1.53 D
Drip irrigation with two laterals/ tree row	1.52 j	1.75 d	1.81 c	1.82 bc	1.72 B	1.61 l	1.72 i	1.79 f	1.86 c	1.74 B
Drip irrigation with rings	1.55 i	1.61 g	1.68 e	1.76 d	1.65 C	1.58 m	1.63 k	1.76 g	1.84 d	1.70 C
Sprinkler irrigation	1.58 h	1.62 g	1.83 b	1.93 a	1.74 A	1.64 k	1.83 e	1.93 b	2.04 a	1.86 A
Mean	1.47 D	1.57 C	1.71 B	1.79 A		1.54 D	1.64 C	1.78 B	1.87 A	
	Plant canopy volume (m^3)									
Single drip irrigation line	3.56 l	3.95 k	5.19 i	5.76 h	4.62 C	4.19 j	4.69 ij	6.11 fgh	8.47 bc	5.86 C
Drip irrigation with tow laterals/ tree row	4.82 j	6.44 f	6.88 e	7.21 c	6.34 B	5.68 ghi	6.93 d-g	7.42 cde	7.99 bcd	7.01 B
Drip irrigation with rings	4.80 j	5.69 h	6.97 d	7.79 b	6.31 B	5.48 hij	6.27 e-h	7.83 bcd	8.74 ab	7.08 B
Sprinkler irrigation	5.27 i	5.96 g	7.06 d	8.61 a	6.72 A	6.05 gh	7.39 c-f	8.11 bcd	9.81 a	7.84 A
Mean	4.61 D	5.51 C	6.53 B	7.34 A		5.35 D	6.32 C	7.37 B	8.75 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

The sprinkler irrigation with 30 kg of sheep manure gave the highest number of fruits and yield per plant. These values in the first season were 382.33 fruits and 60.47 kg, and 362.67 fruits and 52.53 kg in the second season (Table 3). The drip irrigation with rings combined with fertilization with a maximum level of 30 kg of manure showed the best fruit weight, length, and diameter. These measurements in the first season were 158.15 g, 9.72 cm, and 5.35 cm, and in the second season they were 144.86 g, 9.64 cm, and 5.60 cm (Table 4). Fruit firmness, fruit volume, and peel weight were desirable when

the ring drip irrigation was combined with fertilization (30 kg of manure). These records in the first season were 10.00, 135.65 cm^3, and 71.53 g; in the second season, they were 9.90, 167.61 cm^3, and 64.13 g (Table 5). Also, the weightiest pulp weight of the fruit was recorded by the same treatment, and these values were 86.61 and 80.73 g for the first and second seasons, respectively (Table 6). However, the full increments in Juice weight were found by sprinkler irrigation and applying 30 kg of sheep manure. Its data were 44.25 and 43.33 g for the first and second seasons, respectively (Table 6). The most significant increases in the number of seeds per fruit and seeds weight per fruit were observed under ring drip irrigation and 30 kg of manure. These findings in the first season were 212.35 seeds and 13.02 g; in the second season, they were 207.17 seeds and 13.89 g (Table 7).

Table 2. Effect of irrigation methods, organic fertilization rates, and their interactions on cladodes area and a cladodes moisture percentage of cactus pear during the 2021 and 2022 seasons

Irrigation methods	**2021**					**2022**				
	Organic fertilizer									
	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Cladodes area (cm^2)									
Single drip irrigation line	274.92 fg	348.32 de	387.26 bcd	417.56 abc	357.02 B	243.54 o	284.56 l	308.73 k	337.52 i	293.59 D
Drip irrigation with two laterals/ tree row	244.73 g	313.07 ef	308.49 ef	419.26 abc	321.39 C	251.50 n	315.40 j	358.85 f	401.22 c	331.74 C
Drip irrigation with rings	291.48 fg	372.46 cd	430.88 ab	466.11 a	390.23 A	278.91 m	344.50 g	398.63 d	457.64 a	369.92 A
Sprinkler irrigation	278.58 fg	305.62 ef	415.06 abc	435.22 ab	358.62 B	309.41 k	342.40 h	374.78 e	424.51 b	362.78 B
Mean	272.43 D	334.87 C	385.42 B	434.54 A		270.84 D	321.72 C	360.25 B	405.22 A	
	Cladodes moisture %									
Single drip irrigation line	89.61 g	90.39 fg	91.64 def	92.02 cde	90.92 B	88.47 g	89.49 fg	90.03 def	91.01 cd	89.75 C
Drip irrigation with two laterals/ tree row	90.67 fg	90.96 ef	92.66 bcd	93.61 ab	91.98 A	89.54 efg	90.72 cde	91.39 bc	92.67 a	91.75 B
Drip irrigation with rings	91.50 def	92.65 bcd	92.16 cde	93.09 abc	92.98 A	90.51 c-f	92.33 ab	92.60 ab	92.81 a	92.06 A
Sprinkler irrigation	91.32 ef	91.55 def	93.49 ab	93.95 a	92.57 A	90.23 c-f	91.03 cd	92.65 a	93.23 a	91.78 A
Mean	90.77 C	91.39 C	92.49 B	93.17 A		89.68 D	90.89 C	91.67 B	92.43 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Table 3. Effect of irrigation methods, organic fertilization rates, and their interactions on the number of fruits/plant and yield (kg)/plant of cactus pear during the 2021 and 2022 seasons

	2021					2022				
	Organic fertilizer									
Irrigation methods	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Number of fruits/plant									
Single drip irrigation line	92.33 i	114.33 i	205.33 gh	232.67 fgh	161.17 C	89.67 i	112.33 i	174.00 gh	230.33 d	151.58 C
Drip irrigation with two laterals/ tree row	115.67 i	131.00 i	201.00 h	252.00 efg	174.92 C	96.00 i	112.67 i	187.67 fg	206.00 ef	150.58 C
Drip irrigation with rings	193.00 h	288.00 cde	300.67 cd	353.00 ab	283.67 B	152.00 h	228.67 de	243.33 d	317.00 b	235.25 B
Sprinkler irrigation	269.33 def	317.00 bc	358.67 ab	382.33 a	331.83 A	241.00 d	291.00 c	347.67 a	362.67 a	310.58 A
Mean	167.58 D	212.58 C	266.42 B	305.00 A		144.67 D	186.17 C	238.17 B	279.00 A	
	Yield (kg)/plant									
Single drip irrigation line	7.39 j	9.57 j	19.23 gh	24.37 fg	15.14 D	7.99 j	11.07 i	17.71 g	26.56 e	15.83 C
Drip irrigation with two laterals/ tree row	9.84 j	12.39 hj	21.49 gh	28.18 ef	17..97 C	7.73 j	9.36 ij	19.68 fg	25.70 e	15.62 C
Drip irrigation with rings	17.71 hi	27.35 ef	31.90 de	42.04 bc	29.75 B	14.58 h	22.57 f	28.22 e	42.66 c	27.01 B
Sprinkler irrigation	28.73 ef	36.58 cd	45.91 b	60.47 a	42.92 A	25.80 e	33.53 d	46.77 b	52.53 a	39.66 A
Mean	15.91 D	21.91 C	29.63 B	38.76 A		14.02 D	19.13 C	28.09 B	36.86 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Table 4. Effect of irrigation methods, organic fertilization rates, and their interactions on fruit weight, fruit length, and fruit diameter of cactus pear during the 2021 and 2022 seasons

Irrigation methods	2021					2022				
	Organic fertilizer									
	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Fruit weight (g)									
Single drip irrigation line	79.98 h	83.75 h	93.62 g	105.25 f	90.65 D	80.48 h	83.11 h	101.78 ef	115.28 d	95.16 D
Drip irrigation with two laterals/ tree row	85.09 h	94.67 g	106.87 ef	111.87 de	99.63 C	89.10 g	98.53 f	104.08 e	124.73 c	104.31 C
Drip irrigation with rings	106.59 ef	115.08 cd	127.98 b	158.15 a	126.95	107.08 e	115.39 d	134.57 b	144.86 a	125.48 A
Sprinkler irrigation	91.71 g	94.95 g	105.83 f	119.09 c	102.90 B	95.95 f	98.72 f	115.98 d	134.56 b	111.30 B
Mean	90.84 D	97.11 C	108.57 B	123.59 A		93.15 D	98.94 C	114.30 B	129.86 A	
	Fruit length (cm)									
Single drip irrigation line	6.86 k	7.19 j	7.67 i	8.27 g	7.49 D	7.05 m	7.31 l	8.74 e	8.84 d	7.98 D
Drip irrigation with two laterals/ tree row	7.27 j	7.23 j	8.69 ef	9.03 cd	8.05 C	7.74 i	8.11 gh	8.07 h	9.01 c	8.23 B
Drip irrigation with rings	8.20 g	8.61 f	9.16 bc	9.72 a	8.92 A	7.57 j	8.18 g	8.52 f	9.64 a	8.48 A
Sprinkler irrigation	7.60 i	7.91 h	8.83 de	9.26 b	8.40 B	7.48 k	7.75 i	8.18 g	9.31 b	8.18 C
Mean	7.48 D	7.73 C	8.59 B	9.07 A		7.46 D	7.84 C	8.37 B	9.20 A	
	Fruit diameter (cm)									
Single drip irrigation line	3.77 k	3.95 j	4.22 i	4.55 g	4.12 D	4.10 m	4.24 l	5.08 e	5.13 d	4.64 D
Drip irrigation with two laterals/ tree row	4.00 j	3.97 j	4.78 ef	4.97 cd	4.43 C	4.50 i	4.71 gh	4.68 h	5.23 c	4.78 B
Drip irrigation with rings	4.51 g	4.74 f	5.04 bc	5.35 a	4.91 A	4.40 j	4.76 g	4.95 f	5.60 a	4.92 A
Sprinkler irrigation	4.19 i	4.35 h	4.86 de	5.10 b	4.62 B	4.34 k	4.50 i	4.75 g	5.41 b	4.75 C
Mean	4.12 D	4.25 C	4.72 B	4.99 A		4.33 D	4.55 C	4.86 B	5.34 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Table 5. Effect of irrigation methods, organic fertilization rates, and their interactions on fruit firmness, fruit volume, and peel weight of cactus pear during the 2021 and 2022 seasons

Irrigation methods	2021					2022				
	Organic fertilizer									
	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Fruit firmness									
Single drip irrigation line	11.96 bc	11.80 c	11.56 cd	11.20 def	11.63 B	11.53 c	11.26 cd	10.47 ef	10.90 def	11.04 B
Drip irrigation with two laterals/ tree row	12.46 b	11.46 cde	10.70 fg	9.66 i	11.07 C	12.66 b	11.13 cd	10.46 ef	8.53 i	10.70 C
Drip irrigation with rings	14.10 a	13.56 a	10.93 efg	10.00 hi	12.15 A	13.56 a	12.80 b	10.40 fg	9.90 g	11.66 A
Sprinkler irrigation	1053 gh	10.40 gh	10.00 hi	8.26 j	9.80 D	10.93 de	10.83 def	10.40 fg	9.30 h	10.36 D
Mean	12.26 A	11.81 B	10.80 C	9.78 D		12.17 A	11.51 B	10.43 C	9.65 C	
	Fruit volume (cm^3)									
Single drip irrigation line	68.62 h	71.71 h	80.29 g	90.12 f	77.68 D	93.09 h	96.12 h	117.84 ef	133.37 d	110.11 D
Drip irrigation with two laterals/ tree row	72.85 h	81.06 g	91.53 ef	95.88 de	85.33 C	103.23 g	113.96 f	121.34 e	144.35 c	120.72 C
Drip irrigation with rings	91.26 ef	98.72 cd	109.82 b	135.65 a	108.86 A	124.01 e	133.60 d	155.85 b	167.61 a	145.27 A
Sprinkler irrigation	78.63 g	81.37 g	90.71 ef	102.03 c	88.18 B	111.16 f	114.29 f	134.14 d	155.69 b	128.82 B
Mean	77.84 D	83.22C	93.09 B	105.92 A		107.87 D	114.49 C	132.29 B	150.25 A	
	Peel weight (g)									
Single drip irrigation line	36.27 g	37.72 g	42.41 e	47.45 d	40.96 C	35.74 i	36.82 i	45.17 ef	51.11 d	42.21 D
Drip irrigation with two laterals/ tree row	38.34 fg	42.68 e	48.17 d	52.77 c	45.49 B	39.47 h	43.73 fg	46.49 e	55.30 c	46.25 C
Drip irrigation with rings	48.00 d	52.07 c	57.91 b	71.53 a	57.38 A	47.50 e	51.01 d	59.63 b	64.13 a	55.57 A
Sprinkler irrigation	41.54 ef	42.99 e	47.71 d	53.67 c	46.48 B	42.54 g	43.67 fg	51.39 d	59.62 b	49.31 B
Mean	41.04 D	43.87 C	49.05 B	56.36 A		41.31 D	43.81 C	50.67 B	57.54 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Table 6. Effect of irrigation methods, organic fertilization rates, and their interactions on pulp weight and juice weight of cactus pear during the 2021 and 2022 seasons

	2021					2022				
	Organic fertilizer									
Irrigation methods	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Pulp weight (g)									
Single drip irrigation line	43.71 g	46.03 g	51.21 e	57.80 d	49.68 D	44.74 i	46.28 hi	56.61 efg	64.16 d	52.95 D
Drip irrigation with two laterals/ tree row	46.75 fg	51.98 e	58.70 d	59.09 d	54.13 C	49.63 h	54.79 fg	58.36 ef	69.43 c	58.05 C
Drip irrigation with rings	58.59 d	63.01 c	70.07 b	86.61 a	69.57 A	59.58 e	64.38 d	74.93 b	80.73 a	69.91 A
Sprinkler irrigation	50.16 ef	51.96 e	58.11 d	65.41 c	56.41 B	53.41 g	55.05 fg	64.58 d	74.94 b	61.99 B
Mean	49.80 D	53.24 C	59.52 B	67.23 A		51.84 D	55.12 C	63.62 B	72.31 A	
	Juice weight (g)									
Single drip irrigation line	22.37 g	23.03 g	23.17 g	24.61 g	23.29 C	21.47 hi	23.53 ghi	26.11 g	30.63 f	25.44 C
Drip irrigation with two laterals/ tree row	23.31 g	29.25 f	34.87 de	37.16 cd	31.15 B	21.11 i	24.38 gh	32.81 ef	37.13 bcd	28.85 B
Drip irrigation with rings	34.75 de	35.33 d	36.06 cd	41.72 ab	38.25 A	35.28 de	37.73 bcd	39.62 bc	40.11 b	39.24 A
Sprinkler irrigation	32.05 ef	37.74 cd	38.97 bc	44.25 a	36.96 A	36.53 cd	37.61 bcd	39.49 bc	43.33 a	38.18 A
Mean	28.12 D	31.33 C	33.26 B	36.93 A		28.60 D	30.81 C	34.51 B	37.81 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Table 7. Effect of irrigation methods, organic fertilization rates, and their interactions on the number of seeds/fruit and seeds weight/fruit of cactus pear during the 2021 and 2022 seasons

	2021					2022				
	Organic fertilizer									
Irrigation methods	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Number of seeds/fruit									
Single drip irrigation line	103.80 h	111.63 g	125.26 f	141.42 de	120.53 D	104.70 n	112.04 m	133.05 i	146.64 g	124.11 D
Drip irrigation with two laterals/ tree row	114.55 g	127.50 f	140.90 e	146.66 d	132.40 C	114.89 l	124.83 k	133.50 i	157.40 d	132.65 C
Drip irrigation with rings	142.14 de	153.96 c	171.00 b	212.35 a	169.86 A	139.16 h	151.98 e	173.02 c	207.17 a	167.83 A
Sprinkler irrigation	125.83 f	129.91 f	142.09 de	158.76 c	139.15 B	124.62 k	128.25 j	149.85 f	177.45 b	145.04 B
Mean	121.58 D	130.75 C	144.81 B	164.80 A		120.84 D	129.27 C	147.35 B	172.16 A	
	Seeds weight/fruit (g)									
Single drip irrigation line	6.39 k	6.86 j	7.69 h	8.67 f	7.41 D	7.01 o	7.68 n	8.91 j	9.82 g	8.31 D
Drip irrigation with two laterals/ tree row	7.04 i	7.97 g	8.65 f	8.99 e	8.16 C	7.68 m	8.34 l	8.93 i	10.53 d	8.87 B
Drip irrigation with rings	8.72 f	9.48 d	10.48 b	13.02 a	10.42 A	9.32 h	10.18 e	11.61 c	13.89 a	11.25 A
Sprinkler irrigation	7.74 h	7.98 g	8.73 f	9.75 c	8.55 B	8.33 l	8.58 k	10.02 f	11.89 b	9.71 B
Mean	7.47 D	8.07 C	8.89 B	10.11 A		8.08 D	8.65 C	9.87 B	11.53 A	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Regarding fruit chemical attributes, the top fruit T.S.S., fruit T.S.S./acid ratio, and ascorbic acid content were obtained using sprinkler irrigation and 30 kg manure. These detections in the first season were 12.27 %, 27.55, and 15.95 mg/100 ml juice, and in the second season, these values were 12.19 %, 27.13, and 16.47 mg/100 ml juice. Also, the previous treatment gave the minimum fruit total acidity content of 0.44 and 0.45 % for the first and second seasons, respectively (Tables 8 and 9).

Table 8. Effect of irrigation methods, organic fertilization rates, and their interactions on fruit T.S.S. and fruit total acidity content of cactus pear during the 2021 and 2022 seasons

Irrigation methods	2021					2022				
	Organic fertilizer									
	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Fruit T.S.S. (%)									
Single drip irrigation line	10.37 g	10.38 g	10.73 f	11.08 e	10.64 D	10.06 n	10.41 m	10.71 k	10.78 j	10.49 D
Drip irrigation with two laterals/ tree row	10.86 ef	11.52 d	11.78 bcd	11.68 cd	10.82 C	10.91 i	11.34 g	11.81 e	11.98 c	10.86 C
Drip irrigation with rings	10.65 fg	10.78 ef	10.91 ef	10.97 ef	11.93 A	10.61 l	10.80 j	10.91 i	11.15 h	11.94 A
Sprinkler irrigation	11.56 cd	11.85 bc	12.05 ab	12.27 a	11.46 B	11.61 f	11.88 d	12.08 b	12.19 a	11.51 B
Mean	10.86 C	11.13 B	11.36 A	11.50 A		10.79 D	11.11 C	11.37 B	11.52 A	
	Fruit total acidity content (%)									
Single drip irrigation line	0.64 a	0.57 bc	0.55 cde	0.52 ef	0.57 A	0.67 a	0.58 bc	0.57 c	0.51 ef	0.58 A
Drip irrigation with two laterals/ tree row	0.58 b	0.55 cd	0.52 ef	0.49 gh	0.54 B	0.60 b	0.56 cd	0.53 de	0.49 f	0.54 B
Drip irrigation with rings	0.57 bc	0.54 def	0.52 fg	0.49 gh	0.50 C	0.58 bc	0.55 cd	0.53 de	0.51 ef	0.51 C
Sprinkler irrigation	0.55 cde	0.52 ef	0.48 h	0.44 i	0.53 B	0.56 cd	0.53 de	0.49 f	0.45 g	0.54 B
Mean	0.58 A	0.55 B	0.52 C	0.49 D		0.61 A	0.56 B	0.53 C	0.48 D	

Means having the same letter (s) in each row, column or interaction are insignificantly different at 5% level.

Discussion

The organic fertilizer acts as a chelating material for the nutrients deposited in the soil. It reduces the high acidity rate because, during the decomposition of organic matter, many organic acids are produced, which facilitate the absorption of plant nutrients. Using organic fertilizer increases the number of beneficial microorganisms in the soil, and increasing their activity helps significantly facilitate nutrient absorption. The use of organic fertilizer helps improve the soil's structure, which in turn facilitates the absorption of nutrients and avoids their dissipation with irrigation water. With respect to plant

available water, organic fertilizer helps retain water for the most extended possible period (Soloneski and Larramendy, 2019).

Table 9. Effect of irrigation methods, organic fertilization rates, and their interactions on fruit T.S.S./acid ratio and ascorbic acid content of cactus pear during the 2021 and 2022 seasons

	2021					2022				
	Organic fertilizer									
Irrigation methods	0	10 kg	20 kg	30 kg	Mean	0	10 kg	20 kg	30 kg	Mean
	Fruit T.S.S. / acid ratio									
Single drip irrigation line	16.06 l	18.02 k	19.52 hij	21.06 efg	18.66 D	14.87 h	17.86 g	18.80 fg	21.48 cd	18.25 D
Drip irrigation with two laterals/ tree row	18.54 jk	20.71 fgh	22.38 cde	23.70 bc	20.41 C	18.14 g	20.28 de	22.38 c	24.55 b	20.14 C
Drip irrigation with rings	18.59 ijk	19.98 ghi	20.98 efg	22.11 def	23.97 A	18.26 g	19.61 ef	20.55 de	22.16 c	23.74 A
Sprinkler irrigation	21.05 efg	22.52 cd	24.79 b	27.55 a	21.33 B	20.81 de	22.24 c	24.77 b	27.13 a	21.34 B
Mean	18.56 D	20.31 C	21.92 B	23.61 A		18.02 D	20.00 C	21.62 B	23.83 A	
	Ascorbic acid (mg/100 ml juice)									
Single drip irrigation line	14.91 m	15.12 l	15.41 i	15.75 d	15.29 D	15.44 h	15.64 gh	15.93 def	15.92 def	15.73 C
Drip irrigation with two laterals/ tree row	15.19 k	15.35 j	15.51 h	15.82 c	15.47 C	15.71 fg	15.87 efg	16.02 cde	16.33 ab	15.98 B
Drip irrigation with rings	15.42 i	15.62 f	15.74 d	15.86 b	15.77 A	15.95 de	16.13 bcd	16.25 abc	16.39 a	16.28 A
Sprinkler irrigation	15.55 g	15.72 e	15.86 b	15.95 a	15.66 B	16.05 cde	16.24 abc	16.37 a	16.47 a	16.18 A
Mean	15.26 D	15.45 C	15.63 B	15.85 A		15.78 D	15.97 C	16.14 B	16.28 A	

One of the benefits of adding organic fertilizer is that it provides plants with nutrients. It helps to eliminate the formation of hard surface layers that hinder the growth of plants. Organic fertilizer increases plant resistance and immunity to diseases, as the process of bacterial decomposition of organic matter leads to the production of some vitamins and antibiotics, which in turn

help in raising the efficiency of plant immunity. So, organic fertilization promotes sustainable agriculture. Organic fertilization generally improves plant tolerance to diverse abiotic stresses (Soloneski and Larramendy, 2019; Toaima *et al*., 2022).

These results agreed with Vazquez Alvarado *et al*. (2004), who stated that manure contributed to the increase in cactus pears' growth and fruit production. Cruz *et al*. (2015) noticed that the highest dosage of organic fertilizer promoted an increase in fresh and dry matter production compared to the unfertilized treatment and increased water accumulation. According to El Gammal and Salama (2022), increasing organic manure rates resulted in progressive growth, cladodes nutrient content, yield, and fruit quality.

Under these conditions, the best fruit production by sprinkle irrigation may be attributed to the fact that spray irrigation covers a large area of the soil's surface, and small volumes are significant for the cactus pear's shallow and expansive root system (Potgieter, 2001; Snyman, 2004 and 2005; Inglese *et al*., 2010; Paolo *et al*., 2018). Thus, the interaction between the addition of the highest level of sheep manure (30 kg/tree) and sprinkler irrigation had a positive influence on plant canopy volume, number of fruits per plant, fruit yield, and quality due to the availability of water and a slow-release source of nutrients, as previously discussed.

Based on our research in the El-Hammam region of the Northwestern Coast of Egypt, we recommend sprinkler irrigation in the prickly pear orchards and adding 30 kg/tree of sheep manure through the winter season. This will produce the highest yield of fruits that meet the highest possible standards.

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References

Abou-Zaid, F. O., Ahmed, F. and Zedan, A. E. H. I. (2022). Using of prickly pear (*Opuntia* spp.) fruit juice and peels in cookies production. Alexandria Science Exchange Journal, 43:239-248.

Abu-shama, H. S., Ahmed, F. A. and Abd El-magied, H. E. D. (2022). Assessment of jelly candy manufactured from prickly pear fruits (*Opuntia* spp.). World Journal of Advanced Research and Reviews, 16:767-783.

Ahmed, F. A., Fahmy, F. I., Abd El-Wahab, M. A. and Abd El-Azim, W. M. (2023). Effect of chemical fertilization on yield and natural pigments of cactus pears fruits. International Journal of Agriculture & Biology, 29:214-220.

Akinyemi, O. M. (2007). Agricultural Production Organic & Conventional Systems. CRC Press.

AOAC (1995). Association of Official Agricultural Chemists, Official Methods of Analysis, 15th edn. AOAC, Washington, DC, USA.

Barros, J. L. D., Donato, S. L. R., Gomes, V. M., Donato, P. E. R., da Silva, J. A. and Júnior, M. C. P. (2016). Palma forrageira 'Gigante'cultivada com adubação orgânica. Rev Agrotecnol, 7:53-65.

Clarke, G. and Kempson, R. E. (1997). Introduction to the Design and Analysis of Experiments, Arnold, 1St edn. A Member of the Holder Headline Group, London, UK.

Cruz, G. R. B., DE Freitas, P. M. D., Pinho, R. M. A., Santos, E. M. and Ramos, J. P. D. F. (2015). Effects of harvest management and manure levels on cactus pear productivity. Revista Caatinga, 28:135-142.

Donato, P. E., Donato, S. L., Silva, J. A., Pires, A. J., Rosa, R. C. and Aquino, A. A. (2016). Nutrition and yield of 'Gigante'cactus pear cultivated with different spacings and organic fertilizer. Revista Brasileira de Engenharia Agrícola e Ambiental, 20:1083-1088.

Duncan, D. B. (1955). Multiple range and multiple F test. Biometrics, 11:1-24.

El Gammal, O. H. and Salama, A. M. (2022). Effect of organic manure and humic acid on productivity and fruit quality of cactus pear. Egyptian Journal of Desert Research, 72:1-25.

Inglese, P., Mondragon, C. and Nefzaoui, A. (2018). Crop Ecology, Cultivation and Uses of Cactus Pear. FAO, Rome.

Inglese, P., Costanza, P., Gugliuzza, G., Inglese, G. and Liguori, G. (2010). Influence of within-tree and environmental factors on fruit quality of cactus pear (*Opuntia ficus-indica*) in Italy. Fruits, 65:179-189.

Lahbouki, S., Ben-Laouane, R., Anli, M., Boutasknit, A., Ait-Rahou, Y., Ait-El-Mokhtar, M., El Gabardi, S., Douira, A., Wahbi, S., Outzourhit, A. and Meddich, A. (2022). Arbuscular mycorrhizal fungi and/or organic amendment enhance the tolerance of prickly pear (*Opuntia ficus-indica*) under drought stress. Journal of Arid Environments, 199.

Mansour, S. F., Ahmed, F. A. and Tohamy, H. M. (2022). Economic study of growing some succulent plants in Matrouh Governorate, Egypt. Asian Journal of Research in Biosciences, 4:26-38.

Paolo, I.; Nefzaoui, A. and Mondragon, C. (2018). Crop Ecology, Cultivation and Uses of Cactus Pear. Food and Agriculture Organization of the United Nations.

Potgieter, J. P. (2001). Guidelines for the Cultivation of Cactus Pears for Fruit Production, 4th revised edition, Group 7 Trust Printers, Sinoville.

Silva, N. G. D. M. E., Santos, M. V. F. D., Dubeux Júnior, J. C. B., Cunha, M. V. D., Lira, M. D. A. and Ferraz, I. (2016). Effects of planting densityand organic fertilization doses on productive efficiency of cactus pear. Revista Caatinga, 29:976-983.

Snyman, H. A. (2004). Effect of various water application strategies on root development of *Opuntia ficus-indica* and *O. robusta* under greenhouse growth conditions. Journal of the Professional Association for Cactus Development, 6:35-61.

Snyman, H. A. (2005). A case study on in situ rooting profiles and water-use efficiency of cactus pears, *Opuntia ficus-indica* and *O. robusta*. Journal of the Professional Association for Cactus Development, 7:1-21.

Soloneski, S. and Larramendy, M. L. (2019). Organic Fertilizers From Basic Concepts to Applied Outcomes. IntechOpen.

Toaima, W. I. M., Badawy, M. Y. M. A. and Hamed, E. S. (2022). Effect of organic fertilization on productivity of some newly introduced basil varieties under Siwa Oasis conditions. Journal of Applied Biology and Biotechnology, 10:74-88.

Vazquez Alvarado, R. E., Olivares Saenz, E., Zavala Garcia, F. and Valdez Cepeda, R. D. (2004). Utilization of manure and fertilizers to improve the productivity of cactus pear (*Opuntia* spp.) a review. ISHS Acta Horticulturae 728: V International Congress on Cactus Pear and Cochineal.

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