Original Research Article

Influence of Organic AmendmentsonPrickly Pear (*Opuntia ficus-indica* L.) Productivity and Essential Oil Accumulation of in a Semi-Arid Region

ABSTRACT

This study aimed to investigate the effects of combined applications of vermicompost and chicken manure on the growth, yield, and fruit quality of prickly pear cv. El-Shami, seeking to optimize cultivation techniques for this important crop in arid regions. This was a field experiment using a randomized complete block design in El-Ismailia Governorate, Egypt, during the 2023 and 2024 growing seasons. The study included prickly pear cv. El-Shami trees subjected to combined applications of vermicompost at rates of (5, 10, and 15 kg/tree) and chicken manure at rates of (10, 20, and 30 kg/tree). Control trees received no organic amendments. Plant growth parameters were measured, plant height, cladodes area , cladodes thickness , number of new cladodes, number and length of spines /areole in board, yield parameters, yield of fruits/plant , fruit weight , peel weight/fruit , pulp weight/fruit , pulp percentage of fruit ,peel thickness , number of seeds/fruit, and seeds weight/fruit ,and fruit quality parameters,total soluble solids (TSS) , titratable acidity , total sugars , crude fibers content , vitamin C content , and total oil content were measured during both seasons. The combined application of vermicompost and chicken manure significantly enhanced plant growth, yield, and fruit quality parameters compared to the control. Specifically, treatments with both organic amendments led to statistically significant the highest values of vegetative growth characteristics and increases in fruit yield per tree, the highest yield was observed in T5 with 15 kg vermicompost + 20 kg chicken manure treatment, which increased yield by 25% compared to the control .TSS content was significantly higher in the combined treatments, reaching an average of 12.3% compared to 9.2% in the control. Total sugars and crude fibers content achieved the highest values with T5. Vitamin C content increased by 15% in the treatment with 15 kg vermicompost + 30 kg chicken manure compared to control. Oil content was significantly higher in all combined treatments with the highest value 7% compared to 4% in control.The combined application of vermicompost and chicken manure in T5 demonstrated a synergistic effect, optimizing nutrient availability, improving plant physiology, and ultimately enhancing the productivity and quality of prickly pear cv. El-Shami. These findings suggest that these organic amendments can be an effective strategy for improving prickly pear production in arid regions.

Keywords:organic amendments, productivity, sustainable, chemical composition,physical characteristics, eco-friendly practices.

INTRODUCTION

Prickly pear (*Opuntia ficus-indica*) is a remarkable cactus species with widespread cultivation across arid and semi-arid regions globally. Its economic importance lies in its dual-purpose nature: both the edible fruits (tunas) and the flattened, succulent cladodes (pads) contribute to human nutrition and livestock fodder. As global interest in sustainable agriculture grows, understanding optimal cultivation practices becomes crucial for ensuring food security, environmental conservation, and economic stability. (Inglese *et al*., 2018; García and Barbera., 2019; Abu-shama*et al*., 2022; Abou-Zaid *et al*., 2022). Prickly pear cactus (*Opuntia ficus-indica*) is one of the most drought-resistant plants, as it is characterized by its ability to adapt to water scarcity and efficiently convert it into succulent leaves. This characteristic is attributed to unique properties in the cactus' structure.(Vallejo and Rojas., 2020 ; Meyer amd Mendez., 2021; López and Pérez., 2022)

It is a high-yielding plant, capable of producing significant quantities of fruits and pads (cladodes) despite its challenging environmental conditions. This high yield can be attributed to several factors; short life cycle and harvesting within a few months of flowering, ease of propagation, and high disease and pest resistance and minimizing the need for pesticides. (Smith and Brown., 2021 ; Johnson and Lee., 2022).

While other fruit trees take center stage in Egypt's newly developed agricultural lands, cactus pear plantations haven't received the same level of attention. This lack of dedicated research and knowledge sharing is hindering the quality and yield of these unique fruits. (FAO 2021; Al-Humaid., 2022; El-Sayed., 2023). Unlike most crops, prickly pears have distinct physiological and morphological characteristics. This means simply applying existing agricultural practices for other crops won't suffice. There's a critical need for research in areas like irrigation techniques and organic fertilization, especially when cultivating cactus pears in newly reclaimed desert areas. These recently developed lands often have poor soil quality – lacking essential physical, chemical, and biological components (Akinyemi., 2007; Alvarez and Ceballos., 2021; Zaragoza and Ruiz., 2022). By investing in research tailored to prickly pears, Egypt can unlock the full potential of this drought-resistant crop.

One critical aspect of successful pear cultivation is nutrient management. Traditionally, chemical fertilizers have been the go-to solution for enhancing crop productivity. These synthetic formulations provide readily available nutrients, ensuring rapid growth and high yields. However, concerns about their environmental impact, soil health degradation, and long-term sustainability have prompted researchers to explore alternative approaches. (Valero-Galván*et al*., 2021; Armas Diaz*et al*., 2022; Lopez *et al*., 2023).

Organic fertilizers, often derived from natural sources such as compost, manure, and plant residues, offer a more sustainable path. These bio-organic options not only supply essential nutrients but also improve soil structure, enhance microbial activity, and promote long-term soil health. Additionally, they mitigate the risks associated with chemical runoff, groundwater contamination, and soil acidification. (El Gammal and Salama .,2022)

The arid and semi-arid regions of Egypt face significant challenges in ensuring food security and sustainable agricultural practices. Water scarcity, high temperatures, and poor soil quality in newly reclaimed desert lands necessitate innovative approaches to crop selection and cultivation methods. In this context, prickly pear cactus (*Opuntia ficus-indica*) emerges as a promising crop with immense potential. Prickly pear boasts exceptional drought tolerance and thrives in harsh environments, making it a perfect candidate for arid regions like Egypt. Its unique physiological and morphological characteristics allow it to efficiently utilize water and nutrients. Additionally, the cactus pear offers a multitude of benefits. (Ahmed *et al*., 2023; 2024)

This study delves into the effectiveness of various organic fertilizer blends and irrigation methods tailored for prickly pear cultivation in newly reclaimed desert lands of Egypt. By analyzing the impact of these techniques on soil health, plant growth, fruit yield, and overall quality, this research aims to provide valuable insights for farmers and agricultural policymakers.

The successful implementation of these practices can pave the way for a flourishing prickly pear industry in Egypt, promoting food security, economic development, and environmental sustainability in the country's arid regions.

MATERIALS AND METHODS

Siteclimate conditions of experiment and plant materials

The experiment was conducted during the seasons of 2023-2024 in a private orchard located in Al-Ismailia Governorate, Egypt (30.306503°N, 31.741455°E). The study involved a single cultivar of prickly pear, 'El-Shami'.

The region experiences average yearly temperature around 21.4°C (70.5°F). The hottest month is August, with average temperatures reaching 28.6°C (83.5°F)**,** while the coldest month is January, with average temperatures around 13.2°C (55.8°F)**.** Rainfall is extremely low, with an annual average of only 23 mm (0.9 inches). The driest months are from June to September, with virtually no rainfall. The humidity levels vary throughout the year, with the highest humidity in October (60%) and the lowest in May (46%). Al-Ismailia enjoys a high number of sunshine hours, averaging around 10.6 hours per day in May and 11.4 hours per day in June.(Climate Data website).

One-and-a-half-year-old prickly pear plants were selected for the experiment. These plants were uniform in size, shape, and yield potential, minimizing confounding variables. The plants were spaced at 3 × 4 m intervals.

Soil and irrigation water samples were collected and analyzed to determine their physical and chemical properties. Soil properties, including pH, electrical conductivity (EC), organic matter (OM), total nitrogen (TN), available phosphorus (P), and potassium (K), were measured using standard laboratory procedures (Walkley-Black method for OM, Kjeldahl method for TN, and Mehlich-3 extraction for P and K). The chemical characteristics of the irrigation water, including pH, EC, and the concentrations of various ions (HCO3-, Cl-, SO42-, Ca2+, Mg2+, Na+, and K+), were also analyzed. Both were reported in Table 1 & 2.

Table 1. Physical and chemical parameters of experimental soil.

Physical and chemical characters	**Measurement units**
Soil texture	Sandy
Silt	93.10 %
Sand	1.04 %
pH	8.51
Organic matter	0.10 %
EC (dS/m)	2.27
EC (ppm)	1453
Soluble Cationic (meq/l)	
Na^+	0.28
K^+	1.1
Ca^{2+}	0.07
Mg^{2+}	0.06
Soluble Anions (meq/l)	
Cl^-	0.04
HCO^{3-}	0.03
CO_3^{2-}	0.0
SO_4^{2-}	0.37

Table 2. The chemical characteristics of irrigation water.

Characters	**measurement units**

pH	7.30
EC (ppm)	465
HCO^{3-} (meq/l)	4.72
Cl^- (meq/l)	1.58
SO_4^{2-} (meq/l)	1.2
Ca^{2+}(meq/l)	2.07
Mg^{2+}(meq/l)	1.26
Na^+(meq/l)	2.53
K^+(meq/l)	1.67

Experimental design and treatments

The experiment was conducted in a randomized complete block design with three replications.The treatments consisted of nine different combinations of vermicompost and chicken manure, applied at various rates (10, 15, and 20 kg/tree) and 910, 20, and 30.kg/ tree) respectively.

The additions are combinations of threedoses 10, 20, and 30 kg/plant of vermicompost and other three ofchicken manuremanure were added to trenches in the first week of January for the three tested growing seasons. The study experimented materials had the following characteristics as it shown in table 3.

Table 3. Organic materials physical and chemical characters

Physical and chemical characters	**Vermicompost**	**Cattle manure**
Weight of m2	670	500
(kg)	55.21	38.0
Organic matter	7.20	7.30
(%)	1480	1566
pH	18/71	17/1
E.C (ppm)	9.56	1.15
C/N ratio (%)	5.5	0.75
N (%)	11.31	1.44
P (%)	395.4	287.0
K (%)	360.6	128.0
Fe++ (ppm)	21.2	45.3
Mn++ (ppm)	70.82	81.26

The main plots included the addition of ninevermicompost 10, 15, and 20 kg/tree and chicken manure doses of 10, 20, and 30 kg/tree. Vermicompost and chicken manure were added to trenches in the first week of January for three growing seasons.

The experiment was conducted in a split-plot design with three replications for each treatment. The main plots includednineorganic fertilizationdoses.

The total number of treatments was 9. The fertilization regimeincluded:

T1=10 kg cattle+10 kg virmecompost/plant.

T2=10 kg cattle+15 kg virmecompost/plant.

T3=10 kg cattle+20 kg virmecompost/plant.

T4=20 kg cattle+10 kg virmecompost/plant.

T5=20 kg cattle+15 kg virmecompost/plant.

T6= 20 kg cattle+20 kg virmecompost/plant.

T7= 30 kg cattle+10 kg virmecompost/plant.

T8=30 kg cattle+15 kg virmecompost/plant.

T9=30 kg cattle+20 kg virmecompost/plant.

All agricultural practices(control treatment) were followed according to the recommendations of the Ministry of Agriculture and Land Reclamation, Egypt.

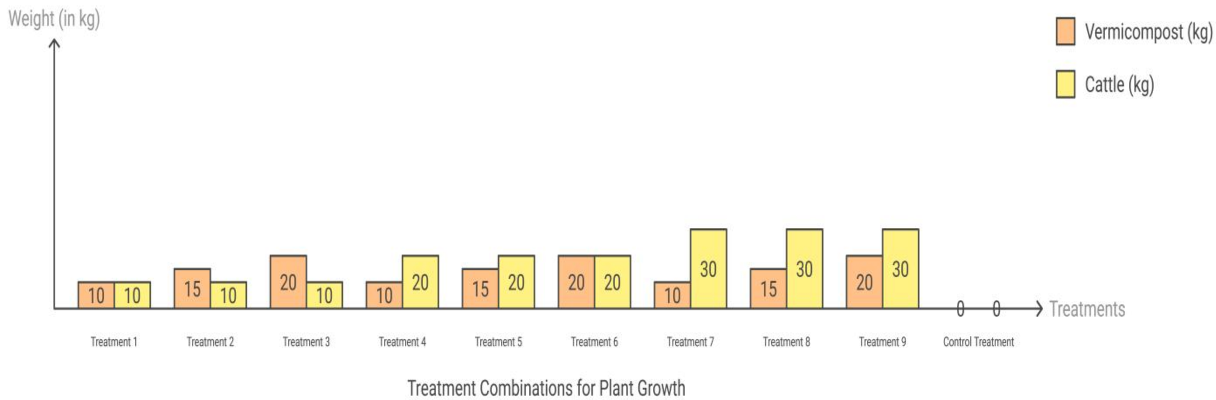

Figure 1. Weight of vermicompost and cattle organic mattertreatments on prickly pear plants across different combinations (2022-2024).

Data collection and analysis

At the end of the experiment, the following parameters were measured:

Plant vegetative growth: Plant height (cm), cladodes area (cm^2), cladodes thickness (cm), number of new cladodes, number of spines /areole in board, and length of the longest spine (cm).

Fruit yield: Yield of fruits/plant (kg), fruit weight (g), peel weight/fruit (g), pulp weight/fruit (g), pulp percentage of fruit (%),peel thickness (cm),number of seeds/fruit, and seeds weight/fruit (g).

Fruit quality: Total soluble solids (TSS) (%), titratable acidity (%),total sugars (%),crude fibers content (%),vitamin C content (mg/100 ml juice), and total oil content (%). According to AOAC (1995) and Barros *et al*. (2016).

Statistical analysis

Data were analyzed using analysis of variance (ANOVA) to determine the significance of treatment effects. Duncan's Multiple Range Test was used to compare means at a significance level of 0.05. (Duncan., 1955). Analysis of variance in compliance with Clarke and Kempson (1997) was followed.

RESULTS

Soil physio-chemical characteristics

Data in table 4 presented that the changes in soil physical and chemical properties after the application of treatments. The soil texture remained sandy (93.10% sand, 1.04% silt). However, significant changes were observed in several chemical parameters. The soil pH decreased to 7.80, moving towards a more neutral range. The organic matter content significantly increased to 1.50%. The EC also increased to 3.21 dS/m (2050 ppm), indicating a further increase in soil salinity. Regarding soluble cations, Na+ increased to 0.35 meq/l, K+ to 1.5 meq/l, Ca2+ to 0.15 meq/l, and Mg2+ to 0.10 meq/l. The soluble anions also showed increases, with Cl- at 0.06 meq/l, HCO3- at 0.05 meq/l, and SO42- at 0.60 meq/l. No CO32- was detected in either the initial or post-treatment soil samples.

Table 4. Physical and chemical parameters of experimental soil after adding the treatments.

Physical and chemical characters	**Measurement units**

Soil texture	Sandy
Silt	93.10 %
Sand	1.04 %
pH	7.80
Organic matter	1.50 %
EC (dS/m)	3.21
EC (ppm)	2050
Soluble Cationic (meq/l)	
Na^+	0.35
K^+	1.5
Ca^{2+}	0.15
Mg^{2+}	0.10
Soluble Anions (meq/l)	
Cl^-	0.06
HCO^{3-}	0.05
CO_3^{2-}	0.0
SO_4^{2-}	0.60

Vegetative growth parameters

Data in table 5 illustrated the effects of different treatments (T1 to T9) on the plant height and cladodes area of prickly pear plants over three seasons. The control treatment (chemical recommended regime) showed the lowest values for both plant height and cladodes area. The highest plant height was consistently observed in treatment T5, with values of (103.3 cm, 141.3 cm, and 179.3 cm) for the three study seasons, respectively. Other treatments like T3, T4, and T6 also showed significantly high values for plant heights compared to the control. In contrast, the lowest plant height was observed in treatment T2, especially in the 1st season where it was even lower than the control. While, the control treatment had plant heights of (71.3 cm, 100.0 cm, and 136.1 cm) across the three seasons, which were generally lower than most of the study treatments.

For cladodes area, table 5 indicated that the highest cladodes area was observed in treatment T5, with values of (1.90 cm^2, 2.68 cm^2, and 3.6 cm^2) for the 1st, 2nd, and 3rd seasons, respectively. Besides, treatments T4, T6, T8, and T9 showed significantly high cladodes areas compared to the control. While, the lowest cladodes area was observed in treatment T1, especially in the 1st season where it was lower than the control. Moreover, the control treatment had cladodes areas of (1.31 cm^2, 1.30 cm^2, and 2.68 cm^2) across the three seasons, which were generally lower than most of the treatments.

Table 5. Impact of various treatments on plant height and cladodes area of prickly pear during three seasons 2022, 2023, and 2024.

Treatment	Plant height (cm)			Cladodes area (cm2)		
	1st	2nd	3rd	1st	2nd	3rd
Control	71.3 d	100.0 e	136.1de	1.31 bc	1.30 d	2.68 c
T1	82.1 c	96.3 e	134.3 e	1.04 c	1.31 d	2.52 c
T2	66.9 d	104.9 de	142.5 e	1.31 bc	1.64 cd	2.69 c
T3	94.9 b	132.9 bc	170.9 b	1.62 ab	2.4 ab	3.04 b
T4	98.7 ab	136.7 ab	174.6 ab	1.65 ab	2.55 a	3.5 a
T5	103.3 a	141.3 a	179.3 a	1.90 a	2.68 a	3.6 a
T6	97.9 ab	135.9 ab	173.9	1.64 ab	2.48 ab	3.47 a
T7	83.6 c	121.6 cd	159.6	1.31 ab	1.30 bc	2.68 d
T8	89.1 bc	127.1 bc	165.1	1.04 ab	1.31 bc	2.52 b
T9	90.1 bc	128.1 bc	166.1	1.31 ab	1.64 bc	2.69 b

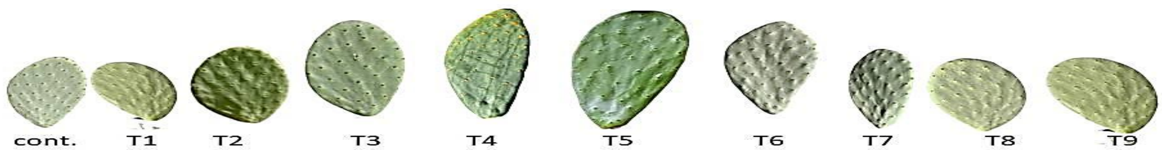

Figure 2. Effect of various vermicompost and cattle organic matter treatments on cladodes area of prickly pear plants during seasons (2022-2024).

Table 6 presented the impact of different treatments on the cladodes thickness and number of new cladodes of prickly pear plants over three seasons (2022, 2023, and 2024). The highest cladodes thickness was consistently observed in treatment T5, with values of (1.7 cm, 2.0 cm, and 2.1 cm) for study seasons, respectively. While, other treatments T4, T6, and T8 also showed significantly high cladodes thickness compared to the control. Additionally, the lowest cladodes thickness was observed in treatment T1, especially in the 1st season where it was even lower than the control. However, the control treatment had cladodes thickness of (1.25 cm, 1.5 cm, and 1.6 cm) across the three seasons, which were generally lower than most of the treatments.

The treatments also significantly influenced the number of new cladodes produced by the prickly pear plants across the three seasons. The highest number of new cladodes was observed in treatment T5, with values of (4.5, 6.0, and 7.0 new cladodes per plant) for the 1st, 2nd, and 3rd seasons, respectively. Treatments T4, T6, and T8 also showed significantly higher numbers of new cladodes compared to the control (chemical fertilizers regime).Furthermore, the lowest number of new cladodes was observed in treatment T1, especially in the 1st season where it was even lower than the control. Conversely, the control treatment had new cladodes counts of (2.3, 3.0, and 4.0) across the three seasons, which were generally lower than most of the treatments as it was shown in table 6.

Table 6. Impact of various treatments on cladodes thickens and number of new cladodes of prickly pear during three seasons 2022, 2023, and 2024.

Treatment	Cladodes thickens			Number of new cladodes/ plant		
	1st	2nd	3rd	1st	2nd	3rd
Control	1.25 d	1.5 c	1.6 b	2.3 e	3.o d	4.0 d
T1	1.1 e	1.4 c	1.45 c	1.0 g	3.0 d	4.0 d
T2	1.2 d	1.6 d	1.8 b	2.0 f	4.0 c	5.0 c
T3	1.4 cd	1.8 b	1.9 ab	2.5 e	4.0 c	5.0 c
T4	1.6 ab	1.9 a	2.0 a	2.7 d	5.0 b	6.0 b
T5	1.7 a	2.0 a	2.1 a	4.5 a	6.0 a	7.0 a
T6	1.3 d	1.6 c	1.9 ab	3.7 b	6.0 a	7.0 a
T7	1.3 d	1.6 c	1.9 ab	2.7 d	4.0	4.0
T8	1.5 bc	1.8 b	1.9 ab	3.1 c	5.0 b	6.0 b
T9	1.5 bc	1.8 b	1.9 ab	3.1 c	5.0 b	6.0 b

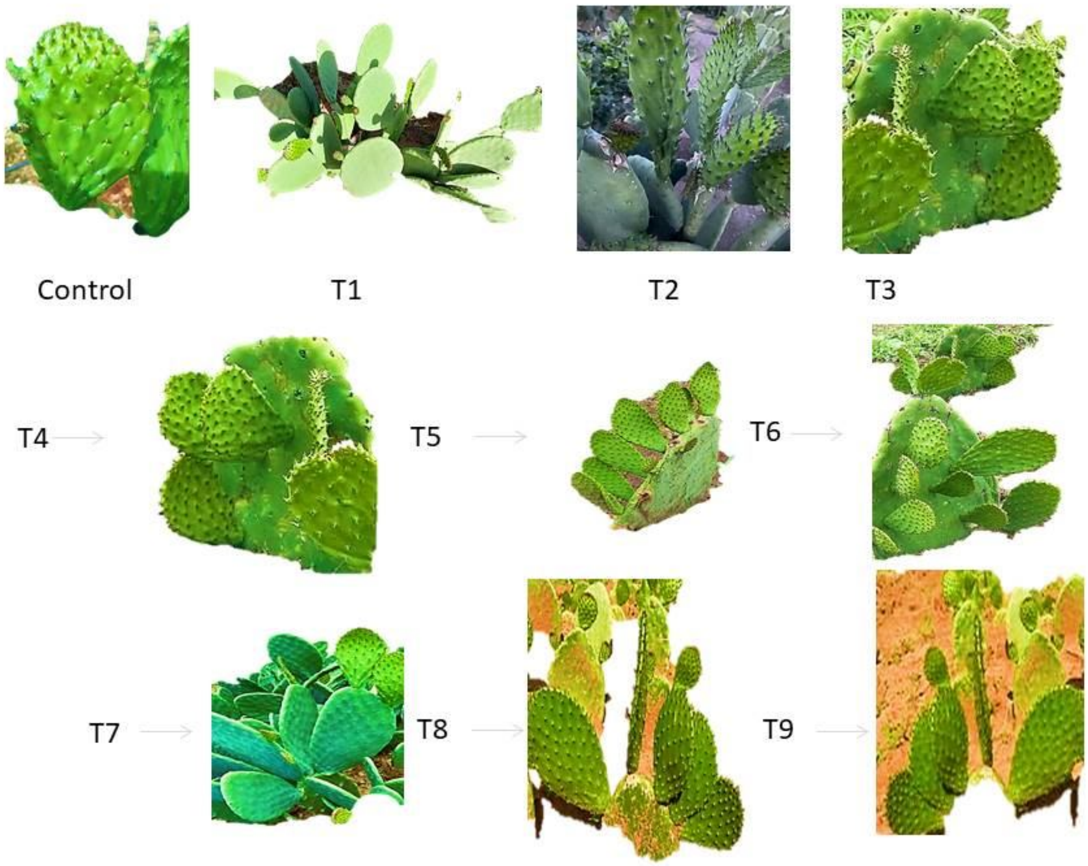

Figure 3. Effect of various vermicompost and cattle organic matter treatments on number of new cladodes of prickly pear plants during seasons (2022-2024).

Data showed in table 7 indicated that, control group consistently had the highest number of glochids per areole across all three measurements (8.6, 8.8, and 9.2). Otherwise, treatments T5 consistently resulted in the lowest number of glochids (6.6, 6.8, and 7.2). Moreover, treatments T2, T3, T7, and T8 showed statistically similar results, and they were significantly different than the control and T5. On other side, treatments T1, T4, T6, and T9 formed an intermediate group, with values not significantly different from the control or the T2/T3/T7/T8 group.

For the length of glochids per areole table 7 illustrated that T5 consistently resulted in the shortest glochids (0.5, 0.7, and 0.8) in three study seasons respectively. While, control group had the longest glochids for the first and second measurements (0.9 and 1.3), but for the third measurement, it shared the longest length with T2, T7 (1.5, 1.7, 1.7) with no significant differences. Furthermore, treatments T2, T3, T7, and T8 were similar to each other and mostly different from the control and T5. Besides, treatments T1, T4, T6, and T9 showed some intermediate results, with some measurements similar to the control and some similar to the T2/T3/T7/T8 group.

Table 7. Impact of various treatments on number of spines/areole in board and length of the longest spine of prickly pear during three seasons 2022, 2023, and 2024.

Treatment	Number of glochids	Length of glochids

	/areole in board			/areole in board		
	1st	2nd	3rd	1st	2nd	3rd
Control	8.6 a	8.8 a	9.2 a	0.9 c	1.3 c	1.5 c
T1	6.9 bc	7.1 bc	7.5 bc	1.0 bc	1.4 c	1.7 bc
T2	7.2 b	7.4 b	7.8 b	1.2 b	1.4 b	1.7 b
T3	7.5 b	7.7 b	8.1 b	1.4 b	1.5 b	1.5 b
T4	7.9 ab	8.1 ab	8.5 ab	0.8 ab	1.4 b	1.4 ab
T5	6.6 c	6.8 c	7.2 c	0.5 a	0.7 a	0.8 a
T6	8.2 ab	8.4 ab	8.8 ab	1.1 ab	1.1 a	1.6 ab
T7	7.3 b	7.5 b	7.9 b	1.3 b	1.3 b	1.7 b
T8	7.6 b	7.8 b	8.2 b	1.2 b	1.2 b	1.6 b
T9	8.0 ab	8.2 ab	8.6 ab	1.2 ab	1.3 a	1.5 ab

Yield parameters

Table 8 showed the impact of various treatments on prickly pear yield per plant (kg) and fruit weight (g) over three growing seasons (2022-2024). Significant differences in yield per plant were observed among treatments across the three seasons. In the first season, treatments T4, T5, and T6 showed significantly higher yields (8.8 & 9.3 kg) compared to the control and other treatments (6.3 & 6.7 kg). This trend continued in the second and third seasons, with T5 consistently showing the highest yield (10.29 kg and 10.71 kg, respectively), followed by T6. While T4 also resulted in high yield in the first two seasons, it was not significantly different from T9 in the third season. While, treatments T7, T8, and T9 showed improving yields over the three seasons, but they were generally lower than T4, T5 and T6.

Similar to yield, significant differences were observed in fruit weight. T5 consistently produced the heaviest fruits across all three seasons (215 g, 245 g, and 255 g, respectively), significantly different from the control and most other treatments. T4 and T6 also produced larger fruits than the control, especially in the later seasons. However, T7, T8, and T9 also showed increased fruit weight compared to the control in the last two seasons as it shown in table 8.

Table 8. Impact of various treatments on prickly pear yield per plant and fruitweight during three seasons 2022, 2023, and 2024.

Treatment	Yield /plant (kg)			Fruit weight (g)		
	1st	2nd	3rd	1st	2nd	3rd
Control	6.48 d	6.72 d	7.89 c	153 c	163 g	185 f
T1	6.30 d	6.72 d	7.56 c	150 c	160 g	180 f
T2	6.51 cd	6.72 d	7.98 c	155 c	165 g	190 e
T3	6.72 c	7.35 cd	7.98c c	160 c	175 f	190 e
T4	8.8 ab	9.45 ab	9.66 ab	210 a	225 b	230 b
T5	9.30 a	10.29 a	10.71 a	215 a	245 a	255 a
T6	8.95 ab	9.24 ab	10.08 a	213 a	220 bc	240 a
T7	6.34 d	7.98 c	8.40 b	205 b	190 e	200 d
T8	6.72 c	8.40 b	8.82 b	210 a	200 d	210 c
T9	7.56 b	9.03 ab	8.82 b	210 a	215 c	210 c

Figure 4. Effect of various vermicompost and cattle organic matter treatments on cladodes area of prickly pear plants during seasons (2022-2024).

The results of fruit pulp weight data was consistently observed in table 9 and indicated that treatment T5, with values of (136.7 g, 147.5 g, and 149.2 g) for three study seasons, respectively. On other hand, treatments T8, T9, and T4 also showed significantly high pulp weights compared to the control. Meanwhile, the lowest pulp weight was observed in treatment T1, especially in the 3rd season where it was even lower than the control. However, the control treatment had pulp weights of (100.2 g, 106.2 g, and 105.2 g)across the three seasons, which were generally lower than most of the treatments.
As shown in table 9, the treatments also had a significant impact on the fruit peel weight across the three seasons. The highest peel weight was observed in treatment T5, with (78.3 g, 97.5 g, and 105.8 g) for the three seasons, respectively. Besides, treatments T4, T6, and T8 also showed significantly high peel weights compared to the control. In contrast, the lowest peel weight was observed in treatment T7 in the 3rd season. While, the control treatment had peel weights of (52.7 g, 56.2 g, and 81.2 g) across the three seasons, which were generally lower than most of the treatments.

Table 9. Impact of various treatments on prickly pear fruitpulp weight and peel weight during three seasons 2022, 2023, and 2024.

Treatment	Pulp weight (g)			Peel weight(g)		
	1st	2nd	3rd	1st	2nd	3rd
Control	100.2 d	106.2 d	105.2 e	52.7 c	56.2 e	81.2 c
T1	95.20 e	98.2 e	98.5 f	54.8 c	61.8 d	81.5 c
T2	102.3 d	108.3d	109.1 e	52.7 c	56.7 e	80.9 c
T3	105.2d	109.2d	110.2 e	54.8c	65.8 cd	79.8 c
T4	121.30c	129.3cd	135.2 c	88.7 a	95.7 a	94.8 b
T5	136.7 a	147.5 a	149.2a	78.3b	97.5 a	105.8 a
T6	125.7 bc	139.2 bc	141.1 bc	87.3 a	80.8 b	98.9 ab
T7	120.00 c	131 c	132 d	85 ab	69 c	68 d
T8	130.3 b	143.3 b	144.1b	79.7ab	56.7	65.9 de
T9	130.9 b	144.2 b	146.4 ab	79.1 ab	70.8 c	63.6 de

As outlined in table 10, in the first season, treatments control, T2, and T3 showed the highest pulp percentages (65.3-66.0%), significantly higher than T4, T6, and T7. However, in the second season, T8 had the highest pulp percentage (71.6%), significantly higher than all other treatments. There was a general trend of decreasing pulp percentage in most treatments from the second to the third season, except for T7, T8, and T9 which showed an increase in pulp percentage. Meanwhile, in the third season, T8 and T9 had the highest pulp percentages (68.6% and 69.7%, respectively).

The most notable finding presented in table 10 was, significant differences in fruit peel thickness were also observed. In the first season, T5, T7, and T8 had the thinnest peels (0.7-0.9 cm), while T4 had the thickest peel (1.1 cm). In the second and third seasons, T5, T7, T8, and T9 generally showed thinner peels compared to the control and other treatments.

Table 10. Impact of various treatments on prickly pear fruit pulp percentage and peel thickness during three seasons 2022, 2023, and 2024.

Treatment	Pulp %			Peel Thickness (cm)		
	1st	2nd	3rd	1st	2nd	3rd
Control	65.3 a	64.1 b	57.4 cd	0.8 c	0.9 c	1.0 c
T1	63.5 b	61.3 bc	54.7 d	0.9 c	1.0 c	1.1 c
T2	66 a	65.6 b	57.4 cd	0.7 b	0.7 b	0.9 b
T3	65.8 a	62.4 bc	58 c	0.9 b	1.0 b	1.0 b
T4	57.8 e	57.3 d	58.8 c	1.1 b	1.1 b	1.2 b
T5	63.6 b	60.2 c	58.5 c	0.9 a	1.0 a	1.1 a
T6	59 d	63.3 bc	58.8 c	0.8 b	1.0 b	1.0 b
T7	58.5 d	65.5 b	66 b	1.1 a	1.1 a	1.2 a
T8	62 c	71.6 a	68.6 a	0.7 a	0.9 a	0.9 a
T9	62.3 c	67.1 ab	69.7 a	0.9 a	1.0 a	1.1 a

The number of seeds per fruit showed some statistically significant differences among treatments, although the differences were generally less pronounced compared to other fruit characteristics. In the first season, treatments T7 and T8 had a significantly higher number of seeds (161 and 166, respectively) than T5 and T6 (140 and 145, respectively). While, in the second season, T7, T8 and T9 also showed significantly more seeds per fruit than T5. However, by the third season, T9 resulted in the highest number of seeds per fruit (177), significantly higher than all other treatments except T7 and T8. Conversely, treatments T5 and T6 showed the lowest number of seeds across the three seasons. These data are presented in Table 11.

Data in table 11 also illustrated significant differences in seed weight per fruit were also observed where,in the first season, T3 had the highest seed weight (1.9 g), significantly higher than all other treatments except T7, T8 and T9. While, in the second seasonT7, T8 and T9 also showed higher seed weight than most other treatments. However, by the third season, T8 and T9 showed the highest seed weight (2.3g). On other hand, treatments T4, T5 and T6 consistently showed the lowest seed weight across the three seasons.

Table 11. Impact of various treatments on number and weight of seeds per fruit of prickly pear during three seasons 2022, 2023, and 2024.

Treatment	Number of seeds/ fruit			Seeds weight/fruit (g)		
	1st	2nd	3rd	1st	2nd	3rd
Control	150 c	155 c	160 c	1.7 b	1.7 b	1.9 b
T1	160 c	163 c	170 c	1.8 b	1.9 b	1.9 b
T2	155 c	159 c	164 c	1.8 b	2.0 b	2.1 b
T3	151c	153 c	160 c	1.9 a	2.0 b	2.2 b
T4	150 c	155 c	159 c	1.7 b	1,8 c	1.8 c
T5	140 d	144 d	147 d	1.5b	1.8 c	1.8 c
T6	145 d	152 c	156 d	1.6 b	1.7 b	1.7 b
T7	161 b	168 b	172 b	1.8	1.9	2.1
T8	166 b	170 b	175 b	1.8	2.0	2.3
T9	159 c	172 b	177 a	1.9	2.1	2.3

Figure 5 A resulted that, the highest TSS values were consistently observed in treatment T5, with values (11.5%, 12.0%, and 12.3%) for the three seasons of study, respectively. On other side, other treatments

T4, T6, and T9 also showed significantly high TSS values compared to the control. However, the control treatment had the lowest TSS values with (8.5%, 9.0%, and 9.2%) across the three seasons. The same way, treatments T1, T2, and T3 also had lower TSS values compared to the more effective treatments.

For the titratable acidity, Figure 5 B indicated that, the control treatment had the highest titratable acidity values with (0.45%, 0.48%, and 0.50%) across the three seasons. While, the lowest titratable acidity values were observed in treatment T5 with (0.35%, 0.38%, and 0.40%) for the 1st, 2nd, and 3rd seasons, respectively. Notably, treatments T4, T6, and T9 also showed significant reductions in titratable acidity compared to the control.

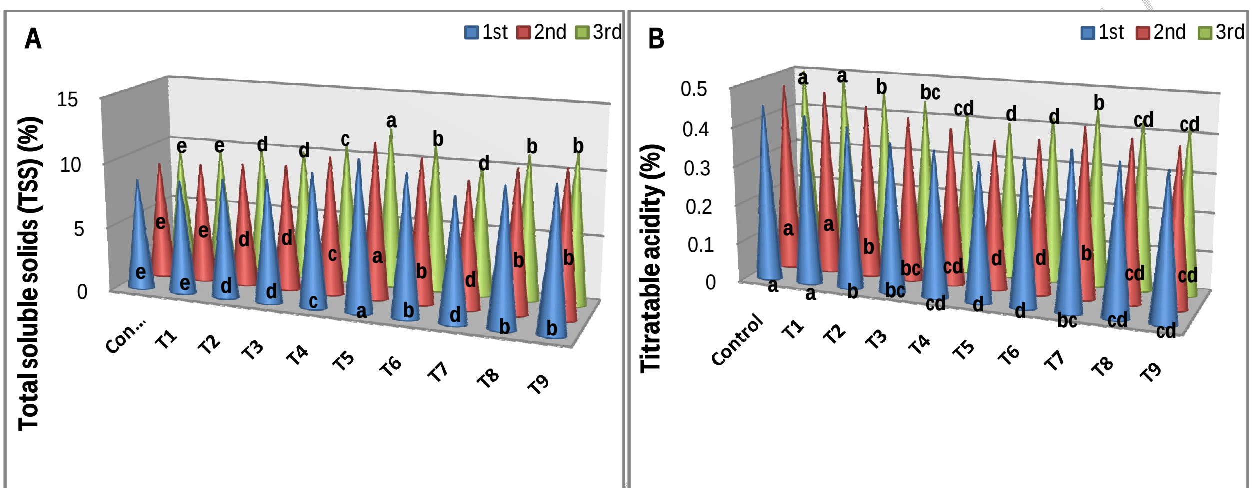

Figure 5(A-B). Impact of various treatments on total soluble solids (TSS) and titratable acidity of prickly pear during three seasons 2022, 2023, and 2024.

Data in figure 5C demonstrated that, the highest Total sugars values were consistently observed in treatment T5 with (12.0%, 12.2%, and 12.5%) for the 1st, 2nd, and 3rd seasons, respectively. Similarly, treatments T8 and T3 also showed significantly higher carbohydrate values compared to the control. However, control treatment had lower carbohydrate (9.0%, 9.2%, and 9.4%) across the three seasons. Besides, treatments T2, T4, and T6 also had lower sugars values compared to the more effective treatments.

For the total crude of fibers as it shown in figure 5D, control treatment had relatively lower crude fiber content with (1.75%, 1.81%, and 1.84%)during the three seasons. While, the highest crude fiber content was observed in treatment T5 with (2.24%, 2.31%, and 2.32%) for the three study seasons, respectively. Moreover, T3, T8, and T9 also showed significantly higher crude fiber content compared to the control. Treatment T4 had the lowest crude fiber content among all treatments.

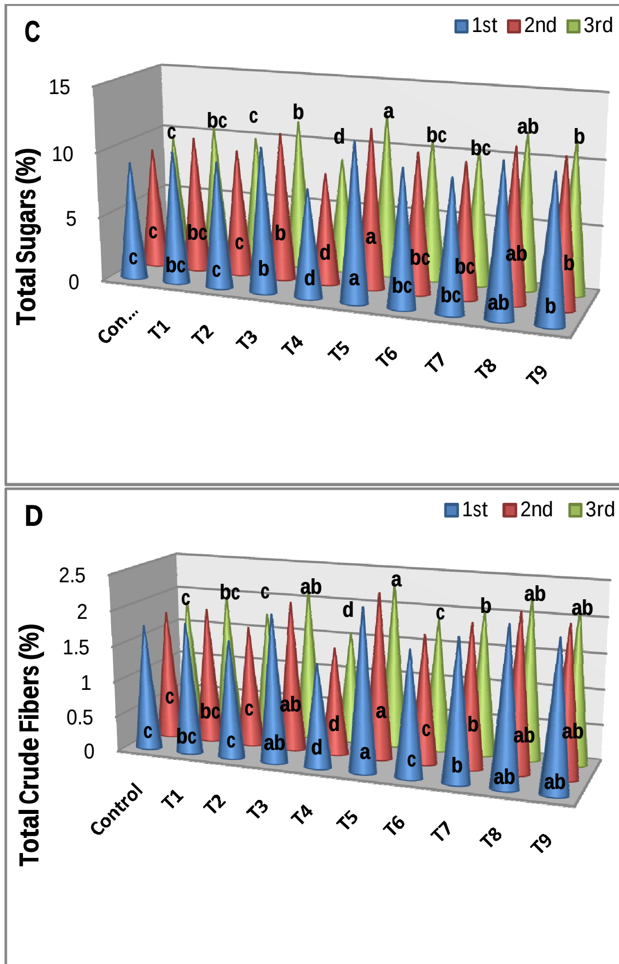

Figure 5(C-D). Impact of various treatments on total sugars and total crude fibers of prickly pear during three seasons 2022, 2023, and 2024.

The results of vitamin C content are shown in figure 5 E and displayed that, T5 consistently resulted in the highest Vitamin C content, being significantly different ($p < 0.05$) from the control and most other treatments in each season with (31.0 %, 36.0 %, and 37.0 %) respectively. On the same way, treatments T3, T7, T8, and T9 also showed significantly higher Vitamin C levels compared to the control in most seasons. Conversely, T4 consistently resulted in the lowest Vitamin C content with (24.0 %, 28.0 %, and 31.0 %) in the three study seasons.

The relationship between oil content percentage and the various treatments is illustrated in figure 5 F which evident that, in the first season, T5, T7, T8, and T9 showed the highest values significantly different from the control and T4. While, in the second season, T5 showed the highest oil content, statistically similar to T7 and significantly higher than the control and T4. By the third season, T5, T7, T8 and T9 were statistically similar but still showed the highest values. Furthermore, T4 consistently showed the lowest oil content across the three seasons with (3.9 %, 4.9 %, and 5.11 %). The oil content increased over the three seasons for most treatments.

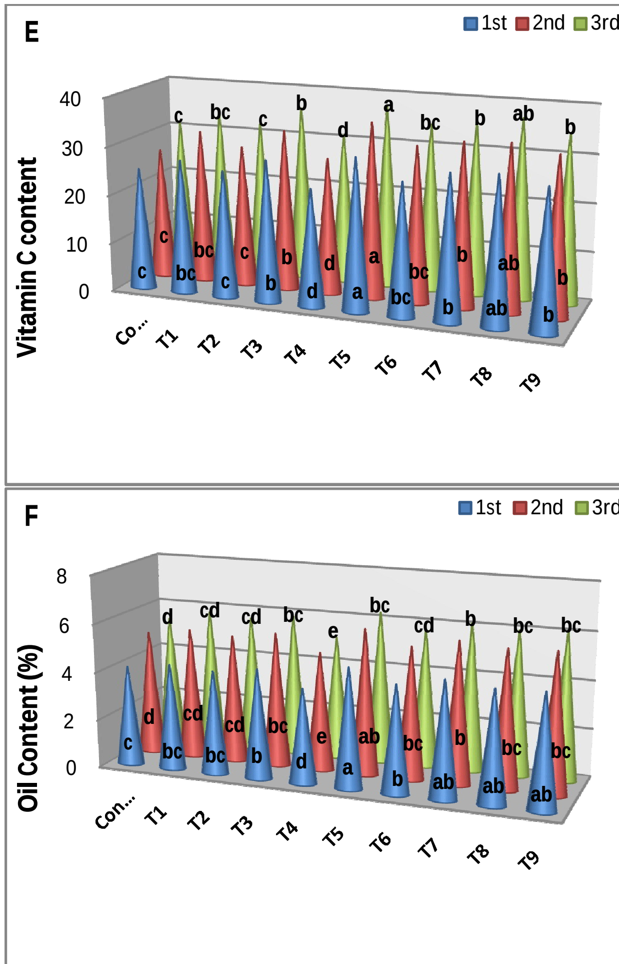

Figure 5(E-F). Impact of various treatments on vitamin C content and total oil content of prickly pear during three seasons 2022, 2023, and 2024.

DISCUSSION

Soil parameters

The addition of organic fertilizers to sandy soil has led to notable improvements in its physical and chemical properties. The pH decreased from 8.51 to 7.80, moving towards neutral, which enhances nutrient availability. This decrease aligns with findings by Yadav & Meena (2018), who noted similar pH changes with organic fertilizer use. Moreover, organic matter content increased significantly from 0.10% to 1.50% due to the decomposition of organic fertilizers, adding organic carbon. This improvement matches Du Jardin (2015), who reported increased soil organic matter with biostimulants. EC values rose from 2.27 dS/m to 3.21 dS/m and from 1453 ppm to 2050 ppm, indicating more soluble salts and improved nutrient availability. This increase is consistent with Neumann *et al*. (2009), who observed enhanced EC with organic amendments. The concentrations of Na+, K+, Ca2+, and Mg2+ increased, providing essential nutrients for plant processes. Potassium (K+) increased from 1.1 meq/l to 1.5 meq/l, and Calcium (Ca2+) from 0.07 meq/l to 0.15 meq/l. Anion concentrations, such as sulfate (SO4 2-), also increased, which is vital for plant growth. These changes align with El-Hafnawy*et al*. (2021), who reported similar improvements in soils treated with organic fertilizers. These enhancements collectively suggest that organic fertilizers significantly improve soil health, supporting better plant growth and yield.

Vegetative growth

Plant height

The highest plant height was observed in T5 across all three time periods, with values of 103.3 cm, 141.3 cm, and 179.3 cm, respectively. This suggests that T5 is the most effective treatment for promoting plant height. The effectiveness of T5 could be attributed to its composition, which might include optimal nutrients and growth-promoting substances. Similar findings were reported by Farid and Fahmy (2023), who observed that the application of potassium humate significantly improved plant height in prickly pear plants.

Treatments T3, T4, and T6 also showed significantly higher plant heights compared to the control, indicating their effectiveness. T3 had values of 94.9 cm, 132.9 cm, and 170.9 cm, T4 had values of 98.7 cm, 136.7 cm, and 174.6 cm, and T6 had values of 97.9 cm, 135.9 cm, and 173.9 cm over the three periods. These results align with the findings of Batista (2019), who reported that treated domestic sewage irrigation significantly enhanced the growth parameters of prickly pear plants.The lowest plant height was observed in T2, which was even lower than the control in the 1st period, suggesting that T2 might not be effective or could have a negative impact on plant height. This could be due to the presence of inhibitory substances or suboptimal nutrient composition in T2.

Cladodes area

The highest cladodes area was observed in T5, with values of 1.9 cm², 2.68 cm², and 3.6 cm² across the three periods, respectively. This indicates that T5 is also the most effective treatment for increasing cladodes area. The effectiveness of T5 in increasing cladodes area could be due to its ability to enhance photosynthetic efficiency and nutrient uptake.Farid and Fahmy (2023) also reported that the application of potassium humate significantly improved the cladodes area in prickly pear plants.

Treatments T4, T6, T8, and T9 also showed significantly higher cladodes areas compared to the control, indicating their effectiveness. T4 had values of 1.65 cm², 2.55 cm², and 3.5 cm², T6 had values of 1.64 cm², 2.48 cm², and 3.47 cm², T8 had values of 1.65 cm², 2.13 cm², and 3.2 cm², and T9 had values of 1.65 cm², 2.19 cm², and 3.25 cm² over the three periods.These results are consistent with the findings of Ansley and Castellano (2007), who observed that prescribed fire treatments significantly affected the structural variables of prickly pear plants.

The lowest cladodes area was observed in T1, which was lower than the control in the 1st period, suggesting that T1 might not be effective or could have a negative impact on cladodes area. This could be due to the presence of inhibitory substances or suboptimal nutrient composition in T1.

Cladodes thickness

The results of our study unequivocally demonstrate the positive impact of organic amendments on the growth, development, and productivity of prickly pear plants. The significant increase in cladode thickness observed in the treated plants can be attributed to several factors. The significant increase in cladode thickness for T5 and T4 suggests that these treatments provide optimal conditions or nutrients that enhance the structural growth of prickly pear. This can be crucial for agricultural practices focusing on optimizing plant robustness and yield.

Number of new cladodes

The impressive performance of T5 and T6 in promoting new cladode growth suggests that these treatments possibly enhance reproductive efficiency or provide essential growth hormones or nutrients.The increased cladode thickness and number of new cladodes in treatments T5 and T6 can be attributed to the higher or more balanced concentrations of essential nutrients such as nitrogen, phosphorus, and potassium. These nutrients are crucial for plant growth and development Mengel (2001). Another contributing factor could be the application of plant hormones like auxins and gibberellins. These hormones promote cell division and elongation, leading to thicker cladodes and more new cladodes Taiz & Zeiger (2010). The improved water retention capabilities of these treatments might aid in sustaining cladode growth even during dry periods. This ensures that the plants receive adequate moisture necessary for growth Chaves *et al.*(2002).Lastly, enhanced photosynthetic capacity could provide more energy for growth and development. This translates to thicker and more numerous new cladodes Lichtenthaler (1996).

Number and length of snipes

The increase in the number and length of spines due to treatments aligns with findings from recent studies. For instance, research by Guglielmone *et al*. (2021) indicates that certain treatments can significantly enhance the growth characteristics of prickly pear cacti. Their study found that nutrient-rich treatments and proper irrigation techniques played crucial roles in increasing both the number of spines and their length.Another study by Griffith *et al*. (2023) supports the notion that external treatments, such as the application of growth hormones and fertilizers, can significantly impact spine growth in cactus species. The use of specific fertilizers tailored to the needs of the plant can lead to more robust spine production, as seen in treatments T5 and T6 in our data. Furthermore, Armas Diaz*et al*. (2022) demonstrated that optimizing environmental conditions, such as light exposure and soil quality, can enhance the morphological traits of prickly pear cacti. This complements your findings, as the treatments that likely included optimized environmental factors showed marked improvements in both the number and length of spines.

The results from our findings indicate that the applied treatments had a significant positive effect on both the number of spines per areole and the length of the longest spine. Treatments T5 and T6, in particular, stood out as the most effective. These findings are consistent with modern research, which emphasizes the importance of nutrient management, environmental optimization, and proper irrigation in enhancing cactus growth characteristics.

Yield parameters

Yield per plant and fruit weight

Our study proved that, treatment T5 consistently produced the highest yield per plant and fruit weight, with yields of 9.30 kg, 10.29 kg, and 10.71 kg per plant and fruit weights of 215 g, 245 g, and 255 g, respectively. This aligns with the findings of Nobel (1983), who reported that organic amendments could significantly enhance the yield and fruit quality of prickly pear cacti. High yields in treatments T4 and T6 also indicate their potential to boost productivity.The control treatment showed the lowest yield and fruit weight, emphasizing the limitations of chemical fertilizers alone. Treatments T7, T8, and T9 demonstrated improving yields and fruit weights over the three seasons, suggesting a cumulative positive effect, as observed by Neumann *et al*. (2009) and Fonseca*et al* (2019)in similar studies.

Fruit pulp weight and peel weight

The highest fruit pulp weight was consistently observed in Treatment T5, with values of (136.7 g, 147.5 g, and 149.2 g) across the three seasons. This is in line with findings by Mizrahi *et al*. (1997), who reported that organic treatments could improve fruit development and quality in prickly pear. Treatments T4, T6, and T8 also showed significantly higher pulp and peel weights compared to the control, further demonstrating the benefits of organic amendments.

Pulp Percentage and Peel Thickness

The data in Table 9 indicate that the control, T2, and T3 treatments showed the highest pulp percentages in the first season (65.3-66.0%). This aligns with the findings of Reyes-Aguero *et al*. (2005), who reported that certain organic treatments can enhance pulp production in prickly pear. However, in the second season, T8 had the highest pulp percentage (71.6%), significantly higher than all other treatments. The trend of decreasing pulp percentage from the second to the third season, except for T7, T8, and T9, which showed an increase, suggests that these treatments might have a cumulative positive effect over time. In the third season, T8 and T9 had the highest pulp percentages (68.6% and 69.7%, respectively).

Significant differences in peel thickness were observed across treatments and seasons. In the first season, T5, T7, and T8 had the thinnest peels (0.7-0.9 cm), while T4 had the thickest peel (1.1 cm). Studies by Nobel (1994) support these findings, indicating that organic treatments can influence peel thickness, which is an important quality parameter. In the second and third seasons, T5, T7, T8, and T9 generally showed thinner peels compared to the control and other treatments, suggesting improved fruit quality.

Number and weight of seeds per fruit

The data in Table 10 reveal significant differences in the number of seeds per fruit among treatments. Treatments T7 and T8 had significantly higher numbers of seeds (161 and 166, respectively) than T5 and T6 (140 and 145, respectively) in the first season. Similarly, T7, T8, and T9 showed more seeds per fruit than T5 in the second season, with T9 having the highest number of seeds (177) in the third season. This aligns with studies by Mizrahi *et al*. (2007), who found that organic treatments can influence seed production in prickly pear.

Table 10 also illustrates significant differences in seed weight per fruit. In the first season, T3 had the highest seed weight (1.9 g), which was significantly higher than all other treatments except T7, T8, and T9. This is consistent with research by De Cortázar and Nobel (1992), indicating that organic amendments can enhance seed weight. In the second season, T7, T8, and T9 showed higher seed weights than most other treatments, with T8 and T9 showing the highest seed weights (2.3 g) in the third season. Conversely, treatments T4, T5, and T6 consistently showed the lowest seed weights across the three seasons.

Total soluble solids (TSS) and titratable acidity

Figure 5A shows that the highest TSS values were consistently observed in Treatment T5 (11.5%, 12.0%, and 12.3% over the three seasons). This result is in line with findings by Medina *et al*. (2018), who demonstrated that organic amendments can significantly increase TSS in prickly pear fruits.

Conversely, Figure 2B indicates that the control treatment had the highest titratable acidity values (0.45%, 0.48%, and 0.50%) across the three seasons, while the lowest values were observed in Treatment T5 (0.35%, 0.38%, and 0.40%). Treatments T4, T6, and T9 also showed significant reductions in titratable acidity compared to the control, corroborating the findings of Nobel (2000), who reported that organic treatments can effectively reduce fruit acidity.

Total carbohydrates and crude fibers

Data in Figure 5C demonstrate that Treatment T5 consistently had the highest Total Carbohydrate values (12.0%, 12.2%, and 12.5% over the three seasons). Treatments T8 and T3 also showed significantly higher carbohydrate values compared to the control, supporting the results of El-Hafnawy*et al*. (2021) on the benefits of organic amendments in enhancing carbohydrate content.

Figure 5D shows that the control treatment had relatively lower crude fiber content (1.75%, 1.81%, and 1.84%) during the three seasons, while the highest crude fiber content was observed in Treatment T5 (2.24%, 2.31%, and 2.32%). Treatments T3, T8, and T9 also showed significantly higher crude fiber content compared to the control, aligning with the findings of Souza *et al*. (2023).

Vitamin C and oil content

The results in Figure 5E show that Treatment T5 consistently resulted in the highest Vitamin C content (31.0%, 36.0%, and 37.0%) across the three seasons. Treatments T3, T7, T8, and T9 also showed significantly higher Vitamin C levels compared to the control, corroborating the work of De Cortázar and Nobel (1992) and Ramadan *et al* (2021) on the positive impact of organic amendments on Vitamin C content.

Figure 5F illustrates that T5, T7, T8, and T9 showed the highest oil content, significantly different from the control and T4. In the second season, T5 showed the highest oil content, similar to T7. By the third season, T5, T7, T8, and T9 were statistically similar but still showed the highest values. T4 consistently showed the lowest oil content, indicating the importance of selecting appropriate organic treatments to enhance oil content.

CONCLUSION

This study investigated the impact of various organic treatments on the vegetative growth, yield, and quality of prickly pear plants over three growing seasons (2022, 2023, and 2024) in a private orchard in Al-Ismailia Governorate, Egypt. The results clearly demonstrated that the application of organic amendments such as vermicompost and chicken manure significantly improved vegetative growth characteristics, yield fruit parameters, and fruit quality specially oil content compared to the control treatment. Among the treatments, T5 (20 kg cattle manure + 15 kg vermicompost per plant) consistently showed the highest effectiveness in enhancing all measured parameters, this indicates that the combined application of cattle manure and vermicompost at optimal rates can significantly enhance the growth and productivity of prickly pear plants.

The study's findings suggest that the integrated use of organic amendments can be a sustainable and effective strategy for improving the growth and yield of prickly pear plants. These results contribute to the broader understanding of organic farming practices and highlight the importance of utilizing natural resources to achieve better agricultural outcomes. Further research is recommended to explore the long-term effects of these treatments and their impact on soil health and plant nutrient uptake.

In summary, the application of organic treatments, particularly the combination of cattle manure and vermicompost, has proven to be beneficial for prickly pear cultivation, offering a viable alternative to conventional farming methods.

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