Original Research Article

Impact of Vermicompost and Chicken Manure on Prickly Pear (*Opuntiaficus-indica* L.) Productivity and Essential Oil Accumulation in a Semi-Arid Region

ABSTRACT

This study investigated the innovative combination of vermicompost and chicken manure to enhance the productivity and fruit quality of prickly pear (*Opuntiaficus-indica* L.) El-Shamicv in arid regions. The novel approach aims to evaluate the synergistic effects of vermicompost and chicken manure on growth, yield, and fruit quality parameters of prickly pear trees, providing a sustainable solution for improving agricultural productivity in arid and semi-arid regions under water-scarce conditions for this important crop.A three-year field experiment (2022-2024) was conducted in Al-Ismailia Governorate, Egypt, using a randomized complete block design. Prickly pear trees were treated with various combinations of vermicompost (5, 10, and 15 kg/tree) and chicken manure (10, 20, and 30 kg/tree), while a control group received no amendments (chemical fertilizers). Key growthsuch as plant height and cladode area, fruit yield, and fruit quality parameters,total soluble solids (TSS), vitamin C, and oil content were measured.
The combined application of vermicompost and chicken manure significantly improved growth, yield, and fruit quality. The highest yield increase (25%) was observed with the treatment combining 15 kg vermicompost and 20 kg chicken manure. This treatment also resulted in the highest TSS at (12.3%) compared to (9.2%) in the controlNotably, vitamin C content increased by 15% with 15 kg vermicompost + 30 kg chicken manure andoil content peaked at a maximum of 7% across combined treatments compared to 4% in the control.These findings demonstrate the potential of integrating vermicompost and chicken manure to optimize prickly pear production and enhance fruit quality. This sustainable approach can significantly improve agricultural productivityin arid and semi-arid regionsaddressing both food security and environmental conservation in water-scarce environments.

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

INTRODUCTION

Prickly pear (*Opuntiaficus-indica*) is a remarkable cactus species cultivated 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).
Despite the global significance of prickly pear, its cultivation in Egypt, especially in newly developed agricultural lands, remains under-researched. This study aims to fill this gap by investigating the

combined application of organic fertilizers and optimized irrigation methods to enhance prickly pear productivity and fruit quality in arid regions. Specifically, the study focuses on tailoring organic fertilizer blends and irrigation techniques for prickly pear cultivation in newly reclaimed desert lands.

Prickly pear cactus is one of the most drought-resistant plants, capable of adapting to water scarcity and efficiently converting it into succulent leaves. This characteristic is attributed to unique properties in the cactus' structure (Vallejo and Rojas, 2020; Meyer and Mendez, 2021; López and Pérez, 2022). The plant's high yield, ease of propagation, and resistance to diseases and pests further enhance its economic significance (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). Newly reclaimed desert lands often have poor soil quality, lacking essential physical, chemical, and biological components (Akinyemi, 2007; Alvarez and Ceballos, 2021; Zaragoza and Ruiz, 2022). Therefore, there is a critical need for research in areas like irrigation techniques and organic fertilization, particularly for cultivating cactus pears in these regions.

One critical aspect of successful prickly pear cultivation is nutrient management. Traditional reliance on chemical fertilizers has raised concerns about environmental impact and long-term sustainability (Valero-Galván et al., 2021; Armas Diaz et al., 2022; Lopez et al., 2023). Organic fertilizers, 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, mitigating 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. Prickly pear emerges as a promising crop with immense potential due to its exceptional drought tolerance and ability to thrive in harsh environments (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

The experiment was conducted during 2022, 2023, and 2024 seasons in a private orchard located in Al-Ismailia Governorate, Egypt (30.306503°N, 31.741455°E). The region experiences an average yearly temperature of 21.4°C (70.5°F) and very low annual rainfall, averaging 23 mm (0.9 inches). Humidity levels range from 46% to 60% (Climate Data website.).These climate conditions are typical of arid regions and significantly influence prickly pear growth.

Plant materials

The study involved the 'El-Shami' cultivar of prickly pear. One-and-a-half-year-old plants were selected, ensuring uniformity in size, shape, and yield potential. The plants were spaced at 3 × 4 m intervals to minimize variability.

Soil and irrigation water characteristics

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 (TN with Kjeldahl method following AOAC Official Method 992.15 (AOAC International, 2019), 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 utilized a randomized complete block design with three replications for each treatment. Nine treatment combinations were tested involving different rates of vermicompost (10, 15, and 20 kg/tree) and chicken manure (10, 20, and 30 kg/tree). Organic amendments were applied to trenches in the first week of January for three growing seasons (2022-2024).

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 treatment combinations were:

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 as following: (2kg Amouniumsulphate 33.5 % on 4 doses, 1.5 kg calcium nitrate on 2 doses, 1 kg potassium sulphate on 2 doses)/ feddan/year.

Data collection and analysis

Vegetative Growth Parameters: Plant height, cladode area, cladode thickness, number of new cladodes, number of spines per areole, and length of the longest spine.

Fruit Yield Parameters: Yield of fruits per plant, fruit weight, peel weight per fruit, pulp weight per fruit, pulp percentage, peel thickness, number of seeds per fruit, and seed weight per fruit.

Fruit Quality Parameters: Total soluble solids (TSS), titratable acidity, total sugars, crude fiber content, vitamin C content, and total oil content (according to AO)AC, 1995).

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 (Clarke .,1997).

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 cm², 2.68 cm², and 3.6 cm²) 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 cm², 1.30 cm², and 2.68 cm²) 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	174.6ab	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

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

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

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

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 /areole in board			Length of glochids /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	1.2ab	1.3 a	1.5 ab

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

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

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

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

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

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

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

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

Means followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

Figure 1A 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 1 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.

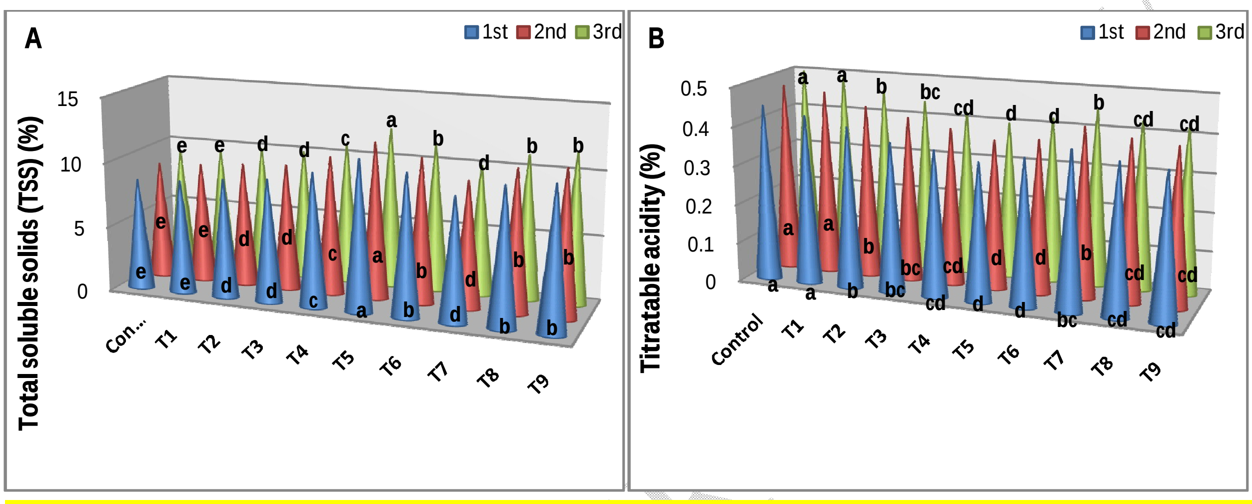

Figure 1 (A-B). Impact of various treatments on total soluble solids (TSS) and titratable acidity of prickly pear during three seasons 2022, 2023, and 2024.

Data in figure 2C 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 2D, 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.

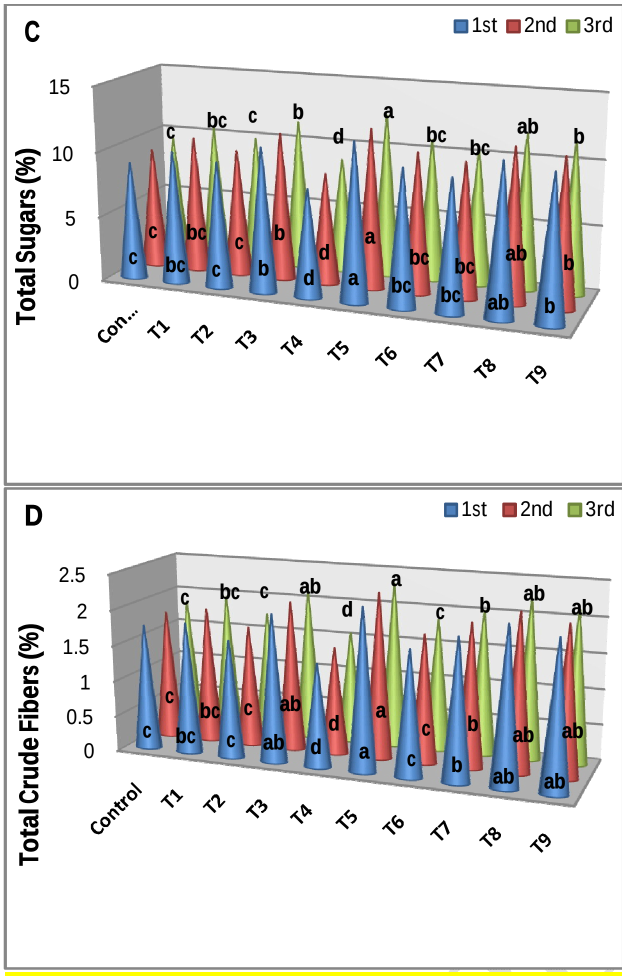

Figure 2 (C-D). Impact of various treatments on total sugars and total crude fibers of prickly pear during three seasons 2022, 2023, and 2024.

The results of vitamin C content are shown in figure 3 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 3 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.

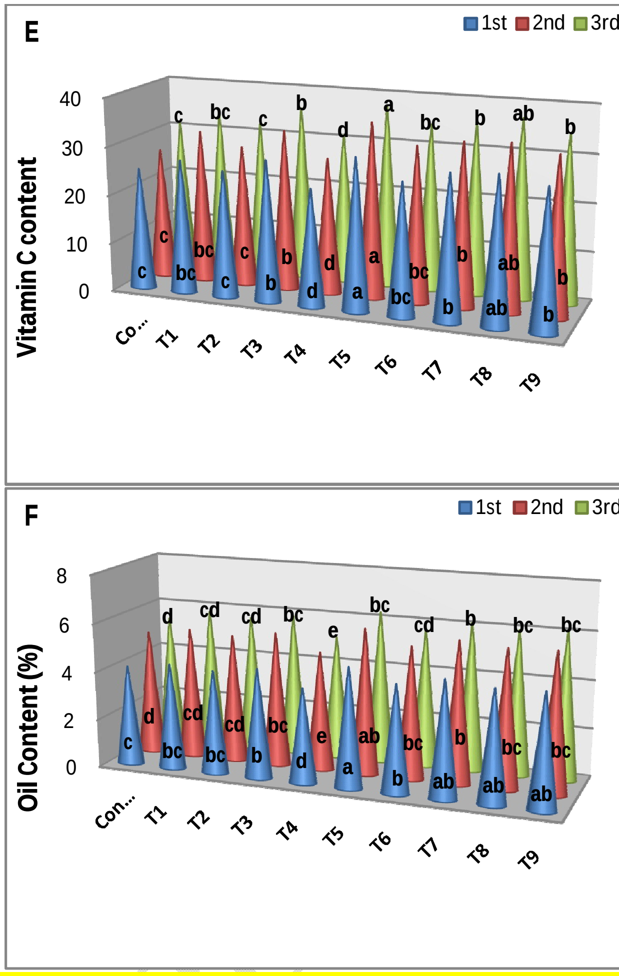

Figure 3 (E-F). Impact of various treatments on vitamin C content and total oil content of prickly pear during three seasons 2022, 2023, and 2024.

DISCUSSION

Soil parameters

The addition of organic fertilizers to sandy soil has significantly improved its physical and chemical properties. The pH decreased from 8.51 to 7.80, moving towards neutrality, which enhances nutrient availability. This decrease aligns with findings by Yadav&Meena (2018), who noted similar pH changes with organic fertilizer use. Furthermore, organic matter content increased substantially 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 bio stimulants.Electrical conductivity (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 essential cations (Na+, K+, Ca^{2+}, and Mg^{2+}) increased, providing vital nutrients for plant processes. Potassium (K^{+}) increased from 1.1 meq/l to 1.5 meq/l, and Calcium (Ca^{2+}) 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. Collectively, these enhancements 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, likely due to its optimal nutrient composition. Farid and Fahmy (2023) observed similar improvements in plant height with the application of potassium humate. Treatments T3, T4, and T6 also showed significantly higher plant heights compared to the control, indicating their effectiveness. 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, even lower than the control in the 1st period, possibly due to suboptimal nutrient composition or inhibitory substances.

Cladodes Area: The highest cladodes area was observed in T5, with values of 1.90 cm², 2.68 cm², and 3.60 cm² across the three periods, respectively. This indicates that T5 is also the most effective treatment for increasing cladodes area, possibly due to its ability to enhance photosynthetic efficiency and nutrient uptake. Farid and Fahmy (2023) also reported significant improvements in cladodes area with the application of potassium humate. Treatments T4, T6, T8, and T9 also showed significantly higher cladodes areas compared to the control, 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, lower than the control in the 1st period, suggesting suboptimal nutrient composition in T1.

Cladodes Thickness: The results of our study unequivocally demonstrate the positive impact of organic amendments on cladodes thickness. 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, 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 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 higher or more balanced concentrations of essential nutrients such as nitrogen, phosphorus, and potassium (Mengel, 2001). Plant hormones like auxins and gibberellins, which promote cell division and elongation, also contribute to this growth (Taiz&Zeiger, 2010). Improved water retention capabilities of these treatments aid in sustaining cladode growth even during dry periods, ensuring adequate moisture (Chaves et al., 2002). Enhanced photosynthetic capacity translates to thicker and more numerous new cladodes (Lichtenthaler, 1996).

Number and Length of Spines: The increase in the number and length of spines due to treatments aligns with findings from recent studies. Research by Guglielmone et al. (2021) indicates that nutrient-rich treatments and proper irrigation techniques significantly enhance the growth characteristics of prickly pear cacti. Griffith et al. (2023) found that external treatments, such as growth hormones and fertilizers, significantly impact spine growth in cactus species. 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. Our findings indicate that treatments T5 and T6 were particularly effective, consistent with modern research emphasizing the importance of nutrient management, environmental optimization, and proper irrigation in enhancing cactus growth characteristics.

Yield parameters

Yield per Plant and Fruit Weight: 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 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 aligns 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 is consistent 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). These findings highlight the potential of T8 and T9 in improving pulp production over multiple seasons, aligning with organic treatment studies showing long-term benefits (Reyes-Aguero et al., 2005).

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, 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. These results underscore the importance of organic treatments in achieving desirable peel thickness, which can enhance marketability and consumer preference (Nobel, 1994).

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), 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.

These findings highlight the importance of selecting appropriate organic treatments to optimize seed production and quality in prickly pear. The higher number and weight of seeds observed in treatments T7, T8, and T9 suggest that these treatments may provide the best conditions for seed development, potentially enhancing reproductive success and fruit quality.

Fruit quality parameters

Total soluble solids (TSS) and titratableacidity:Figure 1A 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 aligns with findings by Medina et al. (2018), who demonstrated that organic amendments can significantly increase TSS in prickly pear fruits. Elevated TSS levels are indicative of better fruit quality, enhancing sweetness and flavor profiles, which are crucial for consumer acceptance and marketability.

Conversely, Figure 1B indicates that the control treatment had the highest titratable acidityvalues (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. Lower acidity levels contribute to improved taste and palatability, making the fruits more desirable for consumption.

Total sugars and crude fibers: Data in Figure 2C demonstrate that Treatment T5 consistently had the highest total sugars 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. Increased sugar content enhances the sweetness and overall flavor of the fruits, contributing to higher consumer preference.

Figure 2D 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). Higher fiber content is beneficial for digestive health and adds nutritional value to the fruits, making them more appealing to health-conscious consumers.

Vitamin C and oil content: The results in Figure 3E 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. Increased Vitamin C content boosts the antioxidant properties of the fruits, enhancing their nutritional profile and health benefits.

Figure 3F 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, highlighting the importance of selecting appropriate organic treatments to enhance oil content. Higher oil content can improve the fruit's texture and taste, adding value to the product.

The results of this study underscore the significant benefits of incorporating organic amendments, such as vermicompost and chicken manure, into sandy soils for the cultivation of prickly pear. Notable improvements in soil health, as evidenced by decreased pH, increased organic matter content, and enhanced nutrient availability, support better plant growth and yield. Specifically, treatments like T5 consistently demonstrated superior performance across various parameters, including plant height, cladode area, and thickness, as well as yield per plant and fruit quality attributes such as total soluble solids (TSS), total sugars, crude fibers, Vitamin C, and oil content. These findings align with previous research and suggest that optimal combinations of organic fertilizers can significantly enhance the structural and nutritional quality of prickly pear plants. Therefore, it is recommended that farmers adopt these organic amendments to improve soil health and crop productivity. Additionally, regular monitoring of soil and plant health, tailored fertilization programs, and efficient irrigation techniques should be implemented to maximize the benefits of these treatments. By following these practices, farmers can enhance agricultural sustainability, promote food security, and support the economic viability of prickly pear cultivation in arid and semi-arid regions.

CONCLUSION

This study demonstrated that the application of organic amendments ,vermicompost and chicken manure significantly improved the vegetative growth, yield, and fruit quality of prickly pear plants in a private orchard in Al-Ismailia Governorate, Egypt. Among the various treatments, T5 (a combination of 20 kg cattle manure and 15 kg vermicompost per plant) consistently showed the highest effectiveness in enhancing plant growth and productivity. These results indicated that the integrated use of organic amendments can be a sustainable and effective strategy for optimizing prickly pear cultivation, contributing to better agricultural outcomes.The broader implications of these findings include potential economic benefits through increased yield and improved fruit quality, as well as environmental benefits from reduced reliance on chemical fertilizers. Additionally, the enhanced soil health and nutrient availability resulting from organic amendments support long-term sustainability in agriculture. Further research is recommended to explore the long-term effects of these treatments on soil health and plant nutrient uptake, as well as their impact on other crops. By focusing on the sustainable use of natural resources, this study highlights the importance of organic farming practices in addressing the challenges of modern agriculture.nIn 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 and sustainable alternative to conventional farming methods.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Walkley-Black method**:** [Insert reference to standard method, e.g., USDA Soil Survey Laboratory Methods Manual]

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