 *Egypt. J. Hort.* **Vol. 52**, No. 1, pp. 1-12 (2025)

# Egyptian Journal of Horticulture

https://ejoh.journals.ekb.eg/

## Effect of Some Soil Additions on Growth and Productivity of Dutch Fennel (Foeniculum Vulgare Mill.) Plants Under North Sinai Conditions

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**Abstract**

The current study was carried out in the Baloza area of the North Sinai Governorate, Egypt, throughout two consecutive seasons (2020/2021 and 2021/2022) to determine the impact of biochar (B) and vermicompost (V) as well as their interactions on the yield of fruits and essential oils of Dutch fennel (Foeniculum vulgare Mill) plants. The findings of the interaction indicated that when plants were given a greater level of biochar B2 (4.8 t/ha) in combination with vermicompost V3 (9.6 t/ha), they achieved the significantly highest increments in growth, fruits, and oil yields as well as NPK uptake. Also, the results showed that Trans-anethole, Estragole, L-fenchone, and D-limonene were the main chemical components of the extracted essential oils.

**Keywords:** Fennel, Biochar, vermicompost, productivity, Essential oil.

## Introduction

The powerfully scented and therapeutic plant (Foeniculum vulgare Mill) fennel belongs to the Apiaceae family and indigenous to southern Europe, Asia, the Mediterranean region, and North Africa. Because of their antispasmodic, balsamic, stomachic, sedative, digestive, cardiotonic, lactogogue, and tonic properties, the plants's fruits are used in traditional medicine. It is regarded as a spice because of terpenoid components that were extracted from its oil. The volatile oil is used in the production of pharmaceuticals and cosmetics. The constituents of fennel volatile oil included anethole, limonene, Fenchone, estragole, safrole, α-pinene, camphene, β-pinene, β-myrcene, and P-cymene. (Saleha, 2011, Saravanaperumal and Terza, 2012).

The total fennel cultivated area in 2022 in Egypt was 2881 feddan (686 feddan in new land and 2195 feddan in old land), which produced 3889 tons (674 tons from new land and 2715 tons from old land) with an average 1.176 ton/feddan (0.983 tons / fed. in new land and 1.237 tons / feddan in old land), according to Statistics of the Ministry of Agriculture (2022). Since the bitter fennel of Egypt's cultivar (*Foeniculum vulgare* var. *vulgare*) has a lower Anethole content of roughly 15.75%, the nation views fennel fruits as a significant export spice. Furthermore, the Egyptian variety's high 87.98% Estragole content poses a serious disadvantage. Estragole is one of the substances that cannot be used in pharmaceuticals or baby formulae. Some nations, like Germany, prohibit the use of Egyptian fennel in the general medication production sector. Therefore, it was essential to introduce new varieties of fennel for cultivation in our country (Shalaby et al., 2011, Abd El-Aleem et al., 2017).

In recent years, Heliopolis University Botanical Garden has brought a new genotype of sweet fennel to Egypt, known as Dutch fennel (*Foeniculum vulgare* species *vulgare)*. The Netherlands was the source of the imported seeds. Compared to the native fennel type, the new variety has larger fruit and oil yields, a higher Anethole content, and a lower Estragole content (Shalaby et al., 2011, Abou El-Nasr et al., 2013 and Yousef & Abu El-Leel, 2014).

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(Received 17 September 2024, accepted 28 October 2024)
DOI: 10.21608/EJOH.2024.320905.1277

Recently, chemical fertilizers have become essential for meeting crop nutritional requirements (Sharifi-Ashori-Abadi, 1998). Chemical fertilizer use frequently has a variety of detrimental environmental effects, including air, water, and soil contamination, which raises the cost of producing ecological products. It is essential to employ organic or biofertilizers, that supply nutrients for plants and improve the long-term sustainability of agroecosystems in order to reduce the possibility of these detrimental effects of chemical fertilizers (Mehnaz and Lazarovits, 2006). It is generally acknowledged that there is a substantial correlation between soil fertility and the amount of organic matter in the soil (Melero et al., 2007).

Vermicompost is the term for organic material that may be made from almost any organic waste to provide a beneficial fertilizer and efficient soil conditioner. Also, it is identified to have numerous advantages over other organic fertilizers (livestock dung, poultry manure, etc.) (Kiyasuden et al., 2016). As studies have been conducted, vermicompost has been shown to include a variety of beneficial compounds, including vitamins, hormones, humic substances, and antioxidants, in addition to plant nutrients (Aracon et al., 2008). As a result, it enhances the structure of the soil and creates a favorable atmosphere for plant growth. In addition, it is a substance with a high capacity for exchanging cations and retaining water. Furthermore, it improves the soil's ability to breathe as well. Additionally, it facilitates plants' more effective uptake of soil nutrients by the plants (Ceritoglu et al., 2018).

Biochar is a pyrolyzed biocarbon that can be combined with vermicompost to maximize its usefulness on agricultural lands. Biochar is resistant to breaking down and has a high porosity. Because of these qualities, it has a very high capacity to adsorb nutrients, as a result, when it is mixed with organic fertilizers and added to the soil, it functions as a slow-release and nutrient-capture fertilizer (Kammann et al., 2015, Gul & Whalen, 2016, and Schmidt et al., 2021). The addition of biochar to fertilizers enhances other soil properties, such as slowing down the degradation of soil organic matter and soil microbial functions, by increasing microbial carbon use efficiency and shielding soil organic matter from decomposition (Haider et al., 2020, Schmidt et al., 2017, and Joseph et al., 2021). All of these elements contribute significantly to the improvement of soil quality for crop growth.

The goal of the Egyptian government's work is to reclaim additional land so that more aromatic and medicinal plants can be grown there. Little is currently known about how agricultural methods affect the quantity and quality of Dutch fennel plants growing in the Baloza region of the North Sinai Governorate, which is considered recently reclaimed lands. Therefore, the current study's goal was to determine how different levels of biochar, vermicompost, and their combinations affected the quantitative and qualitative characteristics of Dutch fennel fruits.

## Materials and Methods

The current study was carried out through the two growing seasons of 2020/2021 and 2021/2022 in sandy soil in the Agricultural Experimental Station of the Desert Research Center at Baloza region at the latitudes of 30° 07\ North and the longitude 31° 20\ East, North Sinai Governorate. This research was carried out to investigate the impact of some nature soil additives [Biochar (B) and/or Vermicompost (V)] and their attributes on growth, yield components, essential oil, and some chemical constituents of fennel plants.

The physical and chemical properties of the experimental soil and soil additions were analyzed at the laboratories of the Desert Research Center as described by Jackson (1976) and AOAC (2002). The soil properties were as follows: (Texture class: sandy, pH: 8.38, EC ($dSm^{-1}$): 1.19, available N:10, P:3.65, and K:24 mg/kg). Soil additive analysis is presented in Table (1), and meteorological data of the Baloza area (average of 30 years ago) is shown in Table (2).

Dutch fennel (*Foeniculum vulgare* var. vulgare) seeds were kindly obtained from the Botanical Garden of Heliopolis University. Fennel seeds were planted directly in the experimental soil on November 6th during the two seasons, 50 cm inside hills and 75 cm between rows. Plants were irrigated with water from the El-Salam canal (EC = 1068.8 ppm and pH = 7.35) by using a drip irrigation system with drippers (4 L $h^{-1}$) for one hour every three days. After germination was complete (21 days from sowing), fennel plants were thinned to one plant per hill (26670 plants/ha, the hectare = 2.4 faddan ).

**TABLE 1. Chemical composition of the soil additives.**

| Soil additions | EC ($dSm^{-1}$) | pH | Organic matter (%) | Macronutrients (%) | | | Micronutrients (ppm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N | P | K | Mg | Cu | Fe | Mn | Zn |
| **Compost** | 6.37 | 7.18 | 23.69 | 3.40 | 0.46 | 1.09 | 8640 | 61 | 1457 | 95 | 388 |
| **Vermicompost** | 3.35 | 8.60 | 22.96 | 2.20 | 0.44 | 1.03 | 3687 | 45 | 1625 | 60 | 112 |
| **Biochar** | 0.79 | 7.88 | 76.87 | 1.55 | 0.58 | 0.24 | 944.5 | 28 | 806 | 41 | 45 |

**TABLE 2. Average meteorological data from 30 years ago for the Baloza area.**

| Element | Max. T(°C) | Min. T(°C) | Mean RH (%) | Wind speed | Sunshine, hours | Rs (MJ/ $m^2$/d) | G (MJ/ $m^2$/d) | Ra – G | Total rain (mm) | S =Kpa /°C | Evp = mm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jan.** | 19.30 | 7.80 | 70.0 | 3.97 | 6.60 | 11.6 | -0.35 | 4.75 | 50.0 | 0.10 | 4.77 |
| **Feb.** | 20.50 | 8.60 | 70.0 | 3.97 | 7.60 | 15.0 | 0.00 | 6.72 | 25.0 | 0.10 | 5.17 |
| **Mar.** | 23.80 | 10.50 | 60.0 | 4.10 | 8.30 | 18.8 | 0.70 | 8.87 | 15.0 | 0.12 | 7.16 |
| **April** | 28.00 | 13.50 | 60.0 | 3.87 | 9.20 | 22.4 | 0.18 | 12.11 | 5.0 | 0.13 | 9.66 |
| **May** | 27.50 | 15.00 | 60.0 | 3.60 | 10.40 | 25.3 | 0.35 | 14.05 | 1.0 | 0.17 | 10.02 |
| **June** | 30.00 | 20.00 | 60.0 | 3.60 | 11.90 | 27.9 | 0.53 | 15.97 | 0.0 | 0.19 | 10.56 |
| **July** | 30.00 | 22.50 | 70.0 | 3.92 | 12.00 | 27.8 | 0.18 | 15.32 | 0.0 | 0.20 | 9.77 |
| **Aug.** | 32.50 | 22.50 | 70.0 | 3.60 | 11.30 | 25.7 | 0.18 | 15.32 | 0.0 | 0.22 | 8.58 |
| **Sep.** | 30.00 | 20.00 | 70.0 | 3.28 | 10.40 | 22.2 | -0.35 | 12.86 | 1.0 | 0.19 | 7.05 |
| **Oct.** | 27.50 | 17.50 | 70.0 | 2.81 | 9.20 | 17.7 | -0.35 | 9.10 | 10.0 | 0.17 | 5.88 |
| **Nov.** | 23.00 | 14.00 | 70.0 | 3.04 | 7.40 | 12.9 | -0.56 | 5.95 | 20.0 | 0.13 | 1.58 |
| **Dec.** | 20.00 | 10.00 | 70.0 | 3.69 | 6.50 | 10.9 | -0.49 | 4.39 | 35.0 | 011 | 1.18 |

The experiment included nine treatments, which were combinations between three biochar rates (0, 2.4, and 4.8 t $ha^{-1}$) and three levels from vermicompost (0, 4.8, and 9.6 t/ $ha^{-1}$). The treatments were arranged in a strip plot design with three replicates, the main plots contained biochar rates, and subplots included three levels of vermicompost, which was added during soil preparation before sowing. The compost manure at 47.6 $m^3$/ha was added as a control treatment. Chemical fertilization was applied as the recommended dose for fennel plants according to the Egyptian Ministry of Agriculture: calcium superphosphate (15% $P_2O^5$) at the rate of 715 kg $ha^{-1}$, ammonium sulfate (20.5% N) at the rate of 480 kg $ha^{-1}$, and potassium sulfate (48% $K_2O$) at the rate of 120 kg $ha^{-1}$. Every normal agricultural procedure for cultivating fennel plants was followed when necessary.

*The recorded parameters were:*

*Growth parameters*

The growth parameters were recorded after 120 days from the sowing date as follows: Plant height (cm), branches number per plant, herb fresh weight per plant (g), and herb dry weight per plant (g).

*Yield parameters*

At the harvesting stage (May 15th in both seasons), fruit yield per plant (g) was determined, and then fruit yield per hectare (kg) was calculated as follows: fruit yield per plant (g) × number of plants per hectare / 1000

*Chemical substance parameters*

1. Estimation of percentage essential oil: Using Clevenger-style equipment and hydro distillation for four hours, the essential

oil percentage in the air-dried fruits was estimated (British Pharmacopoeia, 1963).

2. Calculation of the essential oil yield per plant (ml) using the formula: oil percentage × dry weight of fruits per plant.

Estimation of essential oil yield per ha (l) using the formula: oil yield per plant × number of plants/ha.

3. Estimation of essential oil constituents: At the Laboratory of Medicinal and Aromatic Plants, National Research Center, Egypt. The essential oil samples were examined by using a Gas Chromatography-Mass Spectrometry instrument (GC-MS analysis).

*Estimation of macronutrients content*

Following the procedures outlined by Cottenie et al. (1982), samples of fennel plants were collected from each plot, dried in an oven at 60 oC, and digested. The results of the assays for various nutrients were as follows:

1. Measurement of nitrogen was made by using Jackson's (1973) micro-Kjeldahl technique.
2. Phosphorus was measured with a spectrophotometer after being colored using the ammonium molybdate and ascorbic acid method, as per Watanabe and Olson (1965).
3. A flame photometer was used to measure the potassium in accordance with Page et al. (1984).

*Statistical analyses*

The means of the treatments were compared using the least significant difference (L.S.D.) test at $P \leq 0.05$ after all gathered data were subjected to analysis of variance. Version 9 of the statistical program was used to complete the calculations (Analytical Software, 2008).

## Results

*Growth parameters*

From the data presented in Fig. (1), results show that all growth parameters plant height, branches number /plant, herb fresh weight /plant as well as herb dry weight / plant were affected by all biochar treatments. Moreover, all growth parameters decreased significantly by decreasing the biochar rate from B2 (4.8 t/ha) to B1 (2.4 t/ha) in the first and second seasons. Also, the highest value in this regard was obtained from B2 (4.8 t/ha biochar) treatment compared to the other levels.

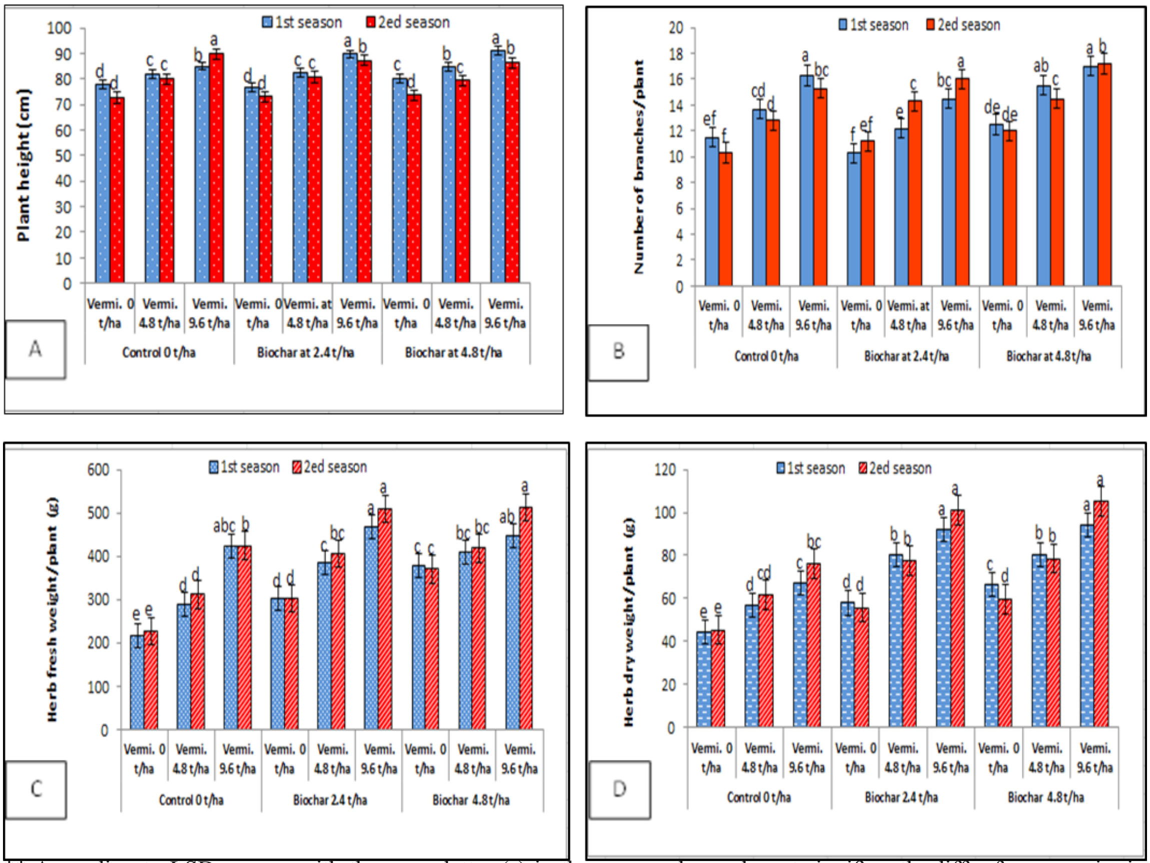
Moreover, vermicompost at rates V2 (4.8 t/ha) and V2 (9.6 t/ha) significantly raised the above- revealed parameters in comparison with control treatment V1 (without vermicompost). When compared to the other treatments under investigation, treatment (V3) was the best in this regard and significantly increased plant height, branch number per plant, fresh weight per plant, and dried weight per plant of the herb. Also, the combination of vermicompost treatments and biochar rates had a substantial impact on plant height, branch counts, fresh weight of the plant, and dried weight of the plant. Generally, the supreme values of all growth characters were attained when added B2 (biochar at 4.8 t/ha) with V3 (vermicompost at 9.6 t/ha) to fennel plants. The lowest values in this regard were noted in interaction treatment between control treatment (without biochar) and (V1), the same behavior was recorded in both seasons.

*Yield components*

Data presented in Fig. 2, Tables 3 and 4, revealed that, biochar levels B1 and B2 induced significant increases in fruit yield and oil yield of the fennel plant and its components as compared with the control treatment. Fruit yield/plant, fruits yield/ha, essential oil percentage and oil yield per plant, as well as oil yield per hectare of fennel plant, significantly increased by increasing the biochar rate in the first and second seasons. The highest values in this respect were achieved from B2 treatment, which recorded a significant increase compared to others.

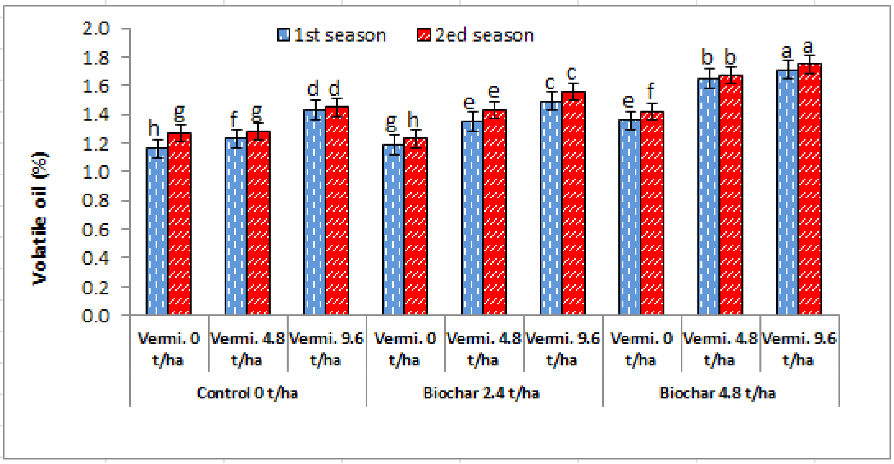
On the other hand, all vermicompost treatments increased significantly all recorded yield parameters (fruits, essential oil percentage, and oil yield per plant as well as per hectare) as compared to control treatment (V1) in both seasons. The highest value in this respect was observed from the treatment of V3, which presented a significant rise in comparison with the other ones under this study.

Furthermore, the combination treatment between B2 and V3 was superior in increasing fruits and oil yields of the fennel plant compared to the other ones under study in the first and second seasons, in most cases. All yield parameters (fruits and oil yield per plant as well as per hectare) were affected by all interaction treatments in both seasons.




** According to LSD, means with the same letter (s) in the same column do not significantly differ for any pairwise comparison test at the 5% probability level.

**Fig. 1. Effect of biochar and vermicompost as well as their interaction treatments on growth parameters of Dutch fennel plants during two seasons (2020/2021 and 2021/2022).**




* * According to LSD, means with the same letter (s) in the same column do not significantly differ for any pairwise comparison test at the 5% probability level.

**Fig. 2. Effect of biochar and vermicompost as well as their interaction treatments on essential oil percentage of Dutch fennel plants during two seasons (2020/2021 and 2021/2022)**

**TABLE 3. Effect of biochar and vermicompost as well as their interaction treatments on yield parameters of Dutch fennel plants during two seasons (2020/2021 and 2021/2022).**

| Biochar (B) as ton / hectare | Vermicompost (V) as ton /hectare | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | V1 (0.0) | V2 (4.8) | V3 (9.6) | Mean (B) | V1 (0.0) | V2 (4.8) | V3 (9.6) | Mean (B) |
| | First season | | | | Second season | | | |
| | | | | Seed yield / plant (g) | | | | |
| **Control (0.0)** | 44.58$^{f}$ | 48.26$^{e}$ | 58.14$^{b}$ | 50.33$^{C}$ | 43.43$^{e}$ | 52.94$^{d}$ | 58.11$^{c}$ | 51.49$^{C}$ |
| **B 1 (2.4)** | 46.92$^{ef}$ | 55.08$^{cd}$ | 58.68$^{b}$ | 53.56$^{B}$ | 50.74$^{d}$ | 54d.87$^{c}$ | 67.59$^{b}$ | 57.73$^{B}$ |
| **B 2 (4.8)** | 52.65$^{d}$ | 57.81$^{bc}$ | 89.09$^{a}$ | 66.52$^{A}$ | 55.14$^{cd}$ | 70.12$^{b}$ | 89.15$^{a}$ | 71.47$^{A}$ |
| **Mean (V)** | 48.05$^{C}$ | 53.72$^{B}$ | 68.64$^{A}$ | | 49.77$^{C}$ | 59.31$^{B}$ | 71.62$^{A}$ | |
| **LSD at 5%** | B=2.13 | V=1.98 | BV=2.79 | | B=4.47 | V=2.09 | BV=5.87 | |
| | | | | Seed yield / ha (kg) | | | | |
| **Control (0.0)** | 1189.00$^{f}$ | 1287.00$^{e}$ | 1550.60$^{b}$ | 1342.20$^{C}$ | 1158.20$^{e}$ | 1412.00$^{d}$ | 1549.80$^{c}$ | 1373.30$^{C}$ |
| **B 1 (2.4)** | 1251.30$^{ef}$ | 1469.10$^{cd}$ | 1565.00$^{b}$ | 1428.40$^{B}$ | 1353.20$^{d}$ | 1463.40$^{cd}$ | 1802.60$^{b}$ | 1539.70$^{B}$ |
| **B 2 (4.8)** | 1404.10$^{d}$ | 1541.9$^{bc}$ | 2376.20$^{a}$ | 1774.10$^{A}$ | 1470.70$^{cd}$ | 1870.00$^{b}$ | 2377.60$^{a}$ | 1906.10$^{A}$ |
| **Mean (V)** | 1281.50$^{C}$ | 1432.70$^{B}$ | 1830.6$^{A}$ | | 1327.40$^{C}$ | 1581.80$^{B}$ | 1910.00$^{A}$ | |
| **LSD at 5%** | B=56.77 | V=52.93 | BV=74.400 | | B=119.16 | V=55.84 | BV=156.59 | |

* * According to LSD, means with the same letter (s) in the same column do not significantly differ for any pairwise comparison test at the 5% probability level.

**TABLE 4. Effect of biochar and vermicompost as well as their interaction treatments on oil yield of Dutch fennel plants during two seasons (2020/2021 and 2021/2022) .**

| Biochar (B) as ton /hectare | Vermicompost (V) as ton /hectare | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | V1 (0.0) | V2 (4.8) | V3 (9.6) | Mean (B) | V1 (0.0) | V2 (4.8) | V3 (9.6) | Mean (B) |
| | First season | | | | Second season | | | |
| | | | | Essential oil / plant (ml) | | | | |
| **Control (0.0)** | 0.543$^{f}$ | 0.680d$^{e}$ | 0.830$^{c}$ | 0.684$^{B}$ | 0.550$^{f}$ | 0.677$^{e}$ | 0.843$^{d}$ | 0.690$^{C}$ |
| **B 1 (2.4)** | 0.530$^{f}$ | 0.653$^{e}$ | 0.877$^{c}$ | 0.687$^{B}$ | 0.623$^{ef}$ | 0.787$^{d}$ | 1.053$^{c}$ | 0.821$^{B}$ |
| **B 2 (4.8)** | 0.713$^{d}$ | 0.953$^{b}$ | 1.523$^{a}$ | 1.063$^{A}$ | 0.780$^{d}$ | 1.170$^{b}$ | 1.560$^{a}$ | 1.170$^{A}$ |
| **Mean (V)** | 0.596$^{C}$ | 0.762$^{B}$ | 1.077$^{A}$ | | 0.651$^{C}$ | 0.878$^{B}$ | 1.152$^{A}$ | |
| **LSD at 5%** | B=0.026 | V=0.037 | BV=0.048 | | B=0.076 | V=0.012 | BV=0.092 | |
| | | | | Essential oil / ha (l) | | | | |
| **Control (0.0)** | 14.477$^{f}$ | 18.130d$^{e}$ | 22.173$^{c}$ | 18.260$^{B}$ | 14.673$^{f}$ | 18.083$^{e}$ | 22.477$^{d}$ | 18.411$^{C}$ |
| **B 1 (2.4)** | 14.113$^{f}$ | 17.380$^{e}$ | 23.387$^{c}$ | 18.293$^{B}$ | 16.650$^{ef}$ | 20.980$^{d}$ | 28.070$^{c}$ | 21.900$^{B}$ |
| **B 2 (4.8)** | 19.100$^{d}$ | 25.447$^{b}$ | 40.643$^{a}$ | 28.397$^{A}$ | 20.857$^{d}$ | 31.243$^{b}$ | 41.620$^{a}$ | 31.240$^{A}$ |
| **Mean (V)** | 15.897$^{C}$ | 20.319$^{B}$ | 28.734$^{A}$ | | 17.393$^{C}$ | 23.436$^{B}$ | 30.722$^{A}$ | |
| **LSD at 5%** | B=0.691 | V=1.047 | BV=1.252 | | B=2.024 | V=0.34$^{7}$ | BV=2.428 | |

* * According to LSD, means with the same letter (s) in the same column do not significantly differ for any pairwise comparison test at the 5% probability level.

*Essential oil constituents*

Effect of different soil additives (biochar and/or vermicompost) on the fennel fruit's essential oil composition Twenty-four compounds were found in the essential oil by GC-MS analysis (representing 97.67–98.96% of the total compositions), trans-anethole was the primary component (44.11–54.79%) of these compounds. (Table 4). Apart from trans-anethole, other prominent constituents identified are estragole (8.74–12.60%), l-Fenchone (9.14-15.40%), α-pinene (3.18–4.89%), and limonene (9.03–13.28%). Monoterpene hydrocarbons (α-pinene, camphene, phellandrene, limonene, terpinene, and sabinene) and phenylpropene derivatives (trans-anethole and estragole) comprised the majority of the essential oil's component groups, accounting for 15.70–20.85% and 52.85–64.62% of the total essential oil composition, respectively. The interaction treatment between biochar at 4.8 t/ha and vermicompost at 9.6 t/ha (B2+V3) had the maximum percentage (54.79%) of trans-anethole in comparison to other treatments, but the minimum percentage in this respect (44.11%) was achieved from treatment that control (without biochar) combined with V3. Also, estragole component was recorded as the maximum percentage (12.60%) from treatment that control + V1, but the minimum value in this regard (8.74%) was obtained from treatment that control (without biochar) + V3.

*4. Chemical components*

From data obtained in Table (6), results show that total NPK contents were affected by all biochar treatments. Furthermore, total NPK contents were decreased significantly by decreasing the biochar rate from B2 (4.8 t/ha) to B1 (2.4 t/ha) in the first and second seasons. Also, the highest value in this regard was obtained from B2 (4.8 t/ha biochar) treatment compared to others.

Moreover, the above-mentioned parameters were considerably higher with vermicompost at rates V2 (4.8 t/ha) and V2 (9.6 t/ha) than with control treatment V1 (no vermicompost).The treatment of (V3) was the best in this regard and provided a significant rise in total NPK contents compared to other treatments under study. Additionally, the combination of vermicompost treatments and biochar rates had a significant impact on total NPK concentrations. Generally, the supreme values of total NPK contents were attained when added B2 (biochar at 4.8 t/ha) with V3 (vermicompost at 9.6 t/ha) to fennel plants, followed by B1 combined with V3 treatment. In contrast, the lowest value in this regard was noted in the interaction treatment between control (without biochar) and (V1), both seasons showed the same behavior.

## Discussion

Vermicompost and biochar are now widely used as significant organic amendments in agricultural production and have been demonstrated to offer certain advantages for enhancing crop yield and soil fertility (Hossain et al., 2020, Tikoria et al., 2022). This may be the consequence of biochar's large specific surface area and mineral content, which allow it to directly absorb nutrients from the soil and minimize nutrient loss. (Li et al., 2023, Lv et al., 2023).

According to the study's findings, adding the natural soil additives (biochar and vermicompost) and their interactions resulted in a significant increase in all fennel growth characteristics, yield, and attributes that were examined, as well as an improvement in the plant's chemical composition that was comparable to that reported by Shi et al. (2020) on maize plant and Hegab (2024) on panicum plant. Additionally, using biochar has benefits for root growth and crop productivity (Manzoor et al., 2022, Wu et al., 2022, Wan et al., 2023, Hafez et al., 2024).

It is evident from the previously described data that the use of biochar treatments had an impact on all growth metrics, yield, and its constituent parts. The best values in this regard were attained when 4.8 t/ha of biochar was applied. These outcomes aligned with the findings published by Hegab (2024) on panicum plants, Anwar et al. (2023), Achakzai et al. (2022), and Khalafalla et al. (2024) on fennel plants, they recorded that the increments in vegetative growth parameters may be due to the biochar clearly affected growth and productivity of the fennel plant. Additionally, it can be because it increases and preserves nutrients, lessens nutrient loss from erosion and/or leaching, improves water absorption, reduces soil compaction, and promotes the growth of advantageous microbes. Bashir et al. (2020) claim that the pyrolysis of biochar releases a number of active compounds that can hasten the growth, development, and yield of plants.

Also, the high NPK uptake may be attributed to the greater solubilization impact of plant nutrients by the biochar application that slowly released more nutrients, ensuring sustainable nutrient availability. These outcomes concur with the findings published by Wang et al. (2012), who indicated that the biochar incorporation in ryegrass significantly improved NPK uptake. In addition, according to Nigussie et al. (2012), the maximum nutrient uptake in soils treated with biochar may also be attributed to an increase in microbial activity brought on by the application of biochar.

According to Figures 1 and 2, Tables 3, 4, and 5, the utilization of vermicompost in this study has been shown to enhance the growth and production characteristics of Dutch fennel. These results are in agreement with those shown by Jankauskiene et al. (2022) on cucumber plants, Beyk-Khormizi et al. (2023), Valiki et al. (2015) on fennel plants, and Ceritoglu et al. (2018). Furthermore, vermicompost produced has been revealed to be effective in the growth and productivity of some aromatic and medical plants, as recorded by Anwar et al. (2005) on basil plants, Chand et al. (2007) on geranium plants, Atiyeh et al. (2002) on marigold plants, and Arancon et al. (2008) on petunia plants. Positive effects of vermicompost on improving crop growth might be due to promoting enzymes that are necessary to chlorophyll production, plant development, and fruit improvement in strawberry (Zuo et al., 2018 and Liu et al., 2021). Vermicompost is the term for organic material that may be made from almost any organic waste to provide a beneficial fertilizer and efficient soil conditioner. Products made from vermicompost provided the soil with organic matter, various hormones, enzymes, and plant nutrients. Therefore, it enhances the structure of the soil and creates an atmosphere that is favorable for plant growth. Vermicompost is a substance with a high capacity for exchanging cations and retaining water. Thus, it improves the soil's ability to breathe as well, and it facilitates plants' better uptake of soil nutrients by the plants (Ceritoglu et al., 2018). The abundance of humic compounds in vermicompost products' structure may also be the primary factor influencing how much nutrient uptake by plants.

Regarding the interaction treatments between biochar and vermicompost, the above results showed that all interaction treatments caused significant increases in all parameters under this study compared to the control treatment. Similar findings were reported by Hegab (2024) on panicum plants.

**TABLE 5. Effect of biochar and vermicompost as well as their interaction treatments on essential oil compositions of Dutch fennel plants.**

| | Compound (%) | RT(min) | without Biochar + without Vermicompost | without Biochar + Vermicompost at 9.6T/ $ha^{-1}$ | Biochar at 4.8 T $ha^{-1}$ + without Vermicompost | Biochar at 4.8 T $ha^{-1}$ + Vermicompost at 9.6T/ $ha^{-1}$ |
|---|---|---|---|---|---|---|
| 1 | α-Thujene | 4.11 | - | 0.06 | 0.19 | 0.01 |
| 2 | 2-Myristynoyl pantetheine | 4.26 | 0.02 | 0.08 | - | 0.12 |
| 3 | α-Pinene | 5.61 | 3.22 | 4.21 | 4.89 | 3.18 |
| 4 | 1,4,6,9-Nonadecatetraene | 5.71 | - | - | 0.25 | - |
| 5 | p-Mentha-1,3,8-triene | 6.22 | - | - | - | 0.17 |
| 6 | Camphene | 7.95 | 0.36 | 0.48 | 0.79 | 0.83 |
| 7 | l-Phellandrene | 10.28 | 1.88 | 2.25 | 1.46 | 1.47 |
| 8 | d-limonene | 11.57 | 9.50 | 13.28 | 9.03 | 9.97 |
| 9 | Terpinene | 12.74 | 0.70 | 0.58 | 0.75 | 1.75 |
| 10 | 5-Tetradecen-3-yne | 13.10 | 0.02 | 0.61 | 0.23 | 0.05 |
| 11 | Sabinene | 13.82 | 0.04 | 0.05 | 1.02 | 0.09 |
| 12 | l-Fenchone | 14.40 | 15.08 | 15.40 | 14.28 | 9.14 |
| 13 | Cineole | 16.45 | - | - | 0.31 | - |
| 14 | Dihexyl terephthalate | 17.98 | 0.15 | - | 0.65 | - |
| 15 | Camphor | 19.38 | 7.19 | 7.56 | 7.60 | 6.47 |
| 16 | Trans-anethole | 19.64 | 47.06 | 44.11 | 45.94 | 54.79 |
| 17 | α-Fenchyl acetate | 19.85 | 0.45 | 0.68 | 0.79 | 0.08 |
| 18 | 4-Terpineol | 21.81 | 0.39 | 0.33 | 0.32 | 0.44 |
| 19 | Linalyl acetate | 21.97 | - | - | - | 0.19 |
| 20 | Estragole | 28.12 | 12.60 | 8.74 | 8.85 | 9.83 |
| 21 | Limonene oxide | 28.26 | 0.12 | - | 0.32 | - |
| 22 | 7-Acetoxy-6-nitrobenzo[a]pyrene | 29.14 | 0.35 | - | - | - |
| 23 | 3-Isopropoxyphthalide | 19.28 | - | 0.14 | - | - |
| 24 | Colchiceine | 30.21 | 0.21 | - | - | - |
| | Total | | 98.96 | 98.42 | 97.67 | 98.58 |
| | Monoterpene Hydrocarbons | | 59.66 | 52.85 | 54.79 | 64.62 |
| | Phenylpropene Derivatives | | 15.7 | 20.85 | 17.94 | 17.29 |

**TABLE 6. Effect of biochar and vermicompost as well as their interaction treatments on total NPK contents/ plant of Dutch fennel plants during two seasons (2020/2021 and 2021/2022).**

| Biochar (B) as ton /hectare | Vermicompost (V) as ton /hectare | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | V1 (0.0) | V2 (4.8) | V3 (9.6) | Mean (B) | V1 (0.0) | V2 (4.8) | V3 (9.6) | Mean (B) |
| | First season | | | | Second season | | | |
| | Nitrogen content (g) | | | | | | | |
| **Control (0.0)** | 0.847 e | 1.113 d | 1.490 c | 1.150 C | 0.908 e | 1.274 d | 1.679 c | 1.286 C |
| **B 1 (2.4)** | 1.166 d | 1.741 b | 2.069 a | 1.659 B | 1.105 d | 1.677 b | 2.285 a | 1.689 B |
| **B 2 (4.8)** | 1.441 c | 1.764 b | 2.144 a | 1.783 A | 1.288 c | 1.746 b | 2.420 a | 1.818 A |
| **Mean (V)** | 1.151 C | 1.539 B | 1.901 A | | 1.100 C | 1.566 B | 2.128 A | |
| **LSD at 5%** | B=0.099 | V=0.170 | BV=0.126 | | B=0.0901 | V=0.349 | BV=0.153 | |
| | Phosphorus content (g) | | | | | | | |
| **Control (0.0)** | 0.092 f | 0.122 e | 0.162 d | 0.126 C | 0.103 f | 0.143 e | 0.180 d | 0.142 B |
| **B 1 (2.4)** | 0.132 e | 0.188 c | 0.218 b | 0.179 B | 0.135 e | 0.194 c | 0.274 b | 0.201 A |
| **B 2 (4.8)** | 0.161 d | 0.198 c | 0.245 a | 0.201 A | 0.145 d | 0.199 c | 0.299 a | 0.214 A |
| **Mean (V)** | 0.128 C | 0.169 B | 0.208 A | | 0.128 C | 0.179 B | 0.251 A | |
| **LSD at 5%** | B=0.012 | V=0.019 | BV=0.015 | | B=0.015 | V=0.046 | BV=0.024 | |
| | Potassium content (g) | | | | | | | |
| **Control (0.0)** | 0.648 e | 0.821 d | 1.010 c | 0.827 C | 0.679 e | 0.920 d | 1.163 c | 0.921 B |
| **B 1 (2.4)** | 0.856 d | 1.219 b | 1.409 a | 1.162 B | 0.857 d | 1.189 b | 1.586 a | 1.211 A |
| **B 2 (4.8)** | 1.004 c | 1.230 b | 1.459 a | 1.231 A | 0.904 c | 1.224 b | 1.656 a | 1.261 A |
| **Mean (V)** | 0.836 C | 1.090 B | 1.293 A | | 0.813 C | 1.111 B | 1.469 A | |
| **LSD at 5%** | B=0.051 | V=0.109 | BV=0.082 | | B=0.057 | V=0.246 | BV=0.111 | |

* * According to LSD, means with the same letter (s) in the same column do not significantly differ for any pairwise comparison test at the 5% probability level.

## Conclusion

This study revealed the benefits of some natural soil additives, such as biochar (B) and vermicompost (V), for increasing Dutch fennel fruit yield and essential oil yield as well as NPK uptake in plants. The results revealed the treatment of biochar at 4.8 t/ha and vermicompost at 9.6 t/ha was the most effective in increasing the productivity of Dutch fennel and improving nutrient uptake. As a result, this treatment seemed to be the recommended to improve growth and increase fennel productivity under North Sinai conditions.

*Acknowledgement*

Not applicable

*Conflicts of Interest*

The author declares no conflict of interest.

*Funding statement*

This study didn't receive any funding support

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## تأثير بعض الإضافات الارضية على نمو و إنتاجية نباتات الشمر الهولندي تحت ظروف شمال سيناء

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**الملخص**

أجريت الدراسة الحالية في منطقة بالوظة بمحافظة شمال سيناء بمصر على مدار موسمين متتاليين 2020/2021 و2021/2022 لدراسة تأثير الفحم الحيوي (B) والسماد الدودي (V) وتفاعلاتهما على محصول الثمار والزيوت العطرية لنباتات الشمر الهولندي (Foeniculum vulgare Mill). أشارت نتائج التفاعل إلى أنه عندما أعطيت النباتات المستوى الأعلى من الفحم الحيوي B2 (4.8 طن / هكتار) مع السماد الدودي V3 (9.6 طن / هكتار)، فقد حققت أعلى الزيادات بشكل ملحوظ في النمو والثمار ومحصول الزيت العطري وكذلك إمتصاص NPK. كما أظهرت النتائج أن Trans-anethole, Estragole, L-fenchone, and D-limonene كانت المكونات الكيميائية الرئيسية للزيوت العطرية المستخرجة.

**الكلمات الدالة:** الشمر، الفحم الحيوي، السماد الدودي، الإنتاجية، الزيوت العطرية.