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Biochar as organic fertilizer and interactive effect of compost tea alternative to mineral fertilization on geranium (*Pelargonium graveolens* L.)

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ABSTRACT

Nowadays, organic fertilizers such as biochar and compost tea have gained a huge interest in sustainable agricultural systems. Two field experiments were conducted during the 2019 and 2020 seasons to study the effect of biochar (BC) as soil applications, compost tea (CT) as foliar applications and their combination on the growth, yield, and essential oil composition of *P. graveolens*. The experimental design was a randomized complete block with three replicates. Three biochar rates (0, 5, and 10 t ha^{-1}) and four compost tea concentrations (0, 0.1, 0.2, and 0.3%) were assigned randomly in plots. Plants were harvested twice; i.e., on 1st May and 30th September, and the following data were recorded for each cut: plant height, leaf area index, fresh herbage yield, oil %, oil yield and chemical constituents of essential oil. Results indicated that *P. graveolens* growth parameters and yield components at both cuts were significantly affected by biochar application and foliar application of compost tea, and a significant interaction of these two factors also occurred. All treatments gave significantly best values of plant height, leaf area index, and fresh herbage yield in addition to essential oil % and oil yield, in comparison with the control treatment. Among treatments, the plants receiving biochar at 10 t ha^{-1} in combination with compost tea 0.1% could be the best choice. The numerical increase in the above-mentioned parameters, in comparison with that of control treatment, reached 115.30, 79.59, 68.85, 66.67 and 181.42%, in the first cut and 118.66, 80.04, 65.81, 66.67 and 176.35% in the second cuts for the tested parameters, respectively. Therefore, this treatment was recommended to achieve the highest yield and excellent quality of essential oil under these experimental conditions. Future investigation is required to determine the optimum doses of biochar and compost tea.

Keywords: Biostimulants, sustainable, medicinal plants, Geraniaceae, growth, essential oil

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1 Introduction

Cultivation of medicinal plants had long a special rank in the traditional agricultural systems of Egypt and these systems have played an important role in creating diversity and sustainability. Rose-scented geranium (*Pelargonium graveolens* L.; Family- Geraniaceae) is a perennial herb; high-value aromatic crop which is cultivated for its essential oil, often considered among the top 20 value-based essential oils produced at the global level. The essential oil of geranium is one of the most valuable natural materials for the cosmetic, perfumery, and pharmaceutical industries (Saraswathi et al., 2011; Boukhris et al., 2012; Tripathi et al., 2021; Mazeed et al., 2022). Egyptian geranium oil globally comes in the second grade after the Reunion Island oil, concerning quality (Lalli et al., 2006; Juliani et al., 2006). It is estimated that about 40% of world production emanates from Egypt and China (Abd El-Wahab et al., 2016; Blerot et al., 2015). Aerial parts (leaves and stems) of *P. graveolens* are an important source of essential oil (EO), phenolic, compounds, coumarins and amines (methylhexanamine) (Saraswathi et al., 2011; Pawar et al., 2013). *P. graveolens* main EO constituents are citronellol (26.21 - 43.17%), geraniol (7.79 - 18.78%), citronellyformate (10.09 - 13.23%), isomenthone (6.11 - 8.05%) and linalool (2.92 - 9.47%) (Abd El-Wahab et al., 2016).

Obtaining the optimum quantity and quality of active ingredients from *P. graveolens* requires the implementation of ecological principles and eco-friendly strategies, as intensive chemical fertilizers use can have a detrimental impact on them (Calamai et al., 2019). The use of organic fertilizers such as biochar and compost tea in modern agriculture is an alternative for reducing chemical fertilizer use and maintaining or increasing soil fertility and plant nutrition. In addition to reducing chemical pollution and maintaining biodiversity by avoiding unnecessary and improper nutrient use, organic fertilizers can reduce production costs and increase input use efficiencies (Mehdizadeh et al., 2020; Mohamed et al., 2022; Rahimzadeh and Ghassemi-Golezani, 2022; Sheikhnazari et al., 2022).

Biochar, as one natural organic fertilizer, is an activated carbon material produced from the pyrolysis of waste biomass and agricultural residues under anaerobic conditions and high temperatures, widely used in soil remediation (Dahlawi et al., 2018; Mansoor et al., 2021). It has received wide attention due to its cost-effectiveness and environmentally-friendly nature. It has been reported that soil amendment with biochar improves soil physicochemical properties including organic matter content, cation exchange capacity, pH, nutrient and water retention, as well as has a promotion effect on soil microbial communities (Uzoma et al., 2011; Singh et al., 2015; Igalavithana et al., 2017; Chen et al., 2021). Improvements in soil fertility by biochar addition have also led to increased crop yield and productivity, the magnitude of response varies with biochar application rates, crop types, soil types, biochar types including feedstock and pyrolysis conditions, and combinations of these factors (Lehmann et al., 2003; Gaskin et al., 2010; Jeffery et al., 2011). Many studies showed that using biochar had an announced promotion on growth, yield, and essential oil quality in different medicinal plants (Pandey et al., 2016; Najafian and Zahedifar, 2018; Agegnehu et al., 2019; Zaefarian et al., 2022; Mumivand et al., 2023).

Compost tea as a processed organic fertilizer is rich in humic acids, growth hormones (auxin and cytokinin), amino acids, enzymes, vitamins, nutrients (N, K, Mg, Zn, Ca, Fe, and Cu) as well as beneficial microorganisms, which can enhance the growth and the productivity of different crops and increase the resistance against diseases (Ibrahim et al., 2018; Osman et al., 2022). It has been reported that foliar application of compost tea was able to enhance the growth, herbage yield, and essential oil and chemical composition of dragonhead (*Dracocephalum moldavica* L.) when sprayed monthly at 0.2% (Ahl and Khalid, 2010).

There is a tendency to produce medicinal plants in sustainable and low input farming systems. However, we assessed a lack of studies about the response of geranium *P. graveolens* to organic fertilizers. Therefore, the objective of this study was to evaluate the effects of biochar and compost tea on growth, essential oil content, and composition of geranium *P. graveolens* plants.

2 Materials and Methods

2.1 Site description, soil, and compost properties

Field experiments were performed during the 2019-2020 and 2020-2021 growing seasons at the private farm (latitude: 31.43ºN, longitude: 31.33ºE and 0.82 m above the Mediterranean Sea level), Zayan, Belqas, Dakahlia governorate, Egypt. Soil analysis properties were provided in Table 1, Meteorological data during the experimental period were obtained from the Egyptian Meteorological Authority (Fig. 1).

2.2 Biochar preparation

Rice straws were collected during the harvesting season of rice in Egypt. The collected straw was washed with tap water to remove any adherent dust and air dried at 40 °C. The biochar (BC) was prepared according to the method described by Cao et al. (2011). The resulting biochar was then ground and sieved through a 0.25 mm mesh before further application.

Table 1. Physical and chemical properties of the soil of experimental site

Properties	Value	Properties	Value
EC (dS m^{-1})*	2.67	Total Ca (%)	0.15
pH**	7.88	Total Mg (%)	0.04
Organic carbon (g kg^{-1})	0.32	Available N (mg kg^{-1})	20.7
CaCo3 (g kg^{-1})	10.22	Available P (mg kg^{-1})	4.35
CEC (cmol kg^{-1})	6.71	Available K (mg kg^{-1})	55.2
WHC (%)	33.34	Exchangeable Ca (mg kg^{-1})	37.7
VW (%)	7.3	Exchangeable Mg (mg kg-$^{-1}$)	22.7
Porosity (%)	31.06	Bulk density (g cm^{-3})	31.06
Total N (%)	0.14	Sand (%)	92.76
Total P (%)	0.03	Silt (%)	5.86
Total K (%)	0.21	Clay (%)	1.38

*Extraction of 1:2 soil: water (w/v). ** Suspension of 1:2 soil: water (w/v). CEC= cation exchange capacity

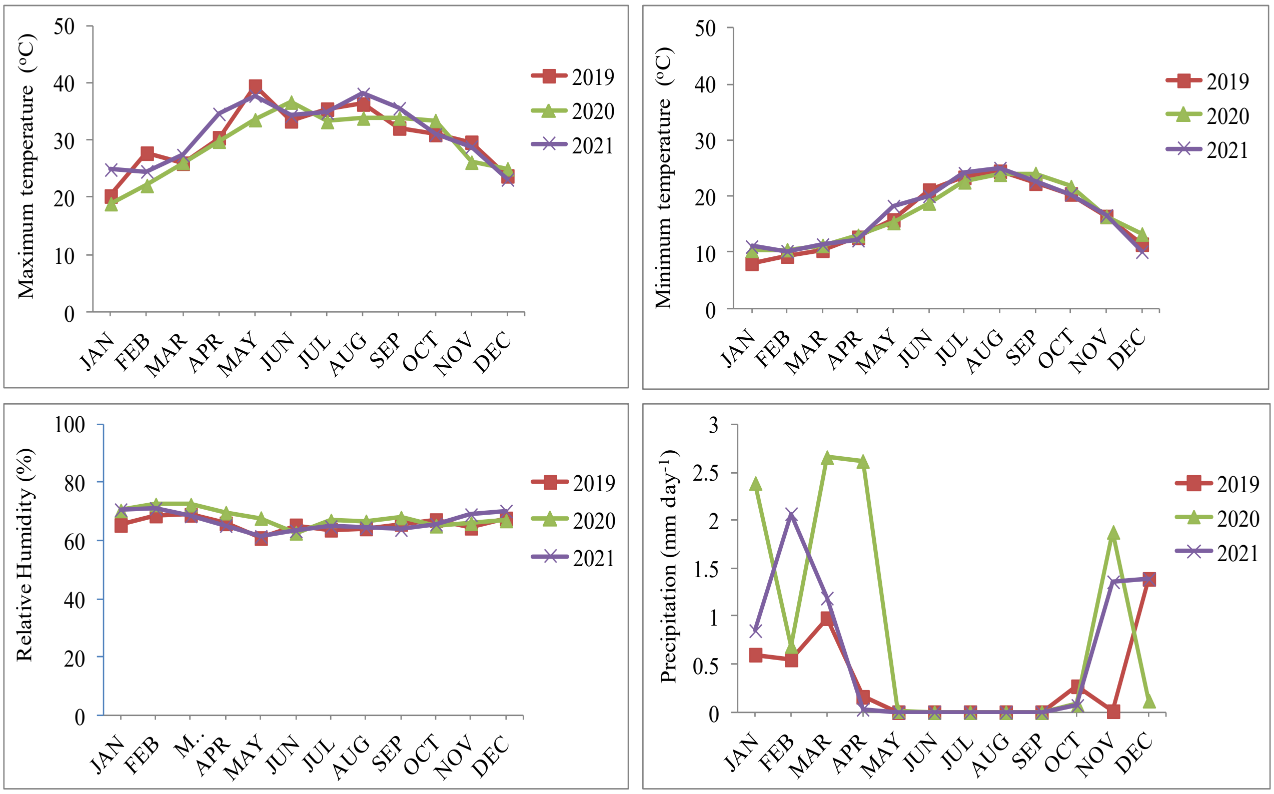

Figure 1. Meteorological data of the experimental site during 2019-2020 and 2020-2021 growing seasons

Some physical and chemical properties of biochar are presented in Table 2.

2.3 Compost tea preparation

Compost product for compost tea extraction was made by Bani suef for Organic Fertilizers Factory. compost tea (CT) produced by mixing compost product with distilled water in three concentrations (0.1, 0.2, 0.3%), incubated during 72 h at 35 °C with daily stirring by an air compressor using a PVC pipe. Then, the liquid mixture was filtered on a 100-mesh and reserved in a refrigerator at 4 °C to become ready to use. Some physic and chemical characteristics, and biological properties of compost were recorded in Table 3.

Table 2. Some chemical properties of biochar (BC)

Properties	Value
Organic carbon (%)	72
Electrical conductivity (EC) dS m^{-1}	1.45
pH	7.74
Cation exchange capacity (CEC) cmole kg^{-1}	59.23
Total available nutrients (%)	
N	2.15
P	0.71
K	5.12
Ca	0.5
Mg	0.3

Table 3. Chemical properties of compost product for compost tea extraction

Properties	Value
pH	7.5
Total count of bacteria (CFU mL^{-1})	9.02×10^8
EC (dS m^{-1} at 25 °C)	6.2
Salinity (%)	7.1
Gibberlic acid (GA) μg mL^{-1}	1.07
Indole-3-acetic acid (IAA) μg mL^{-1}	46.11
Total available nutrients (ppm)	
N	288
P	8.2
K	241
Ca	91.22
Mg	128
Fe	70.31
Zn	9.04
Cu	4

2.4 Layout and design of the experiment

Geranium seedlings (15 cm in height with 5 - 6 leaves) were planted directly in their final position in the second week of November 2019 and 2020. The experimental design was a randomized complete block with three replicates. Three biochar rates (0, 5, and 10 t ha^{-1}) and four compost tea concentrations (0, 0.1, 0.2, and 0.3%) were assigned randomly in plots. Compost tea was sprayed on the plants four times along each season starting 30 days after planting (one month between applications). Biochar was applied before planting. Each plot consisted of four rows, 75 cm apart, and the distance between plants in the row was 50 cm. Irrigation, plant protection, and weed control were carried out when necessary. For both experimental seasons, plants were harvested twice; i.e., on 1st May and 30th September. Plant shoots were cut at 12 cm above the soil surface and the following data were recorded for each cut: plant height (cm), leaf area index (LAI), fresh herbage yield (t ha^{-1}), essential oils %, and oil yield.

2.5 Extraction and analysis of *P. graveolens* oils

P. graveolens essential oil was extracted from fresh herbage through the hydro-distillation method using Clevenger's apparatus according to Guenther (1963) and British Pharmacopoeia (1963). Essential oil % was estimated as (V/W) with the following equation:

$$\text{Essential oil (\%)} = \frac{V}{W} \times 100 \quad (1)$$

where V = volume of oil after the extraction and W = weight of *P. graveolens* fresh herbage used for extraction.
Oil yield was estimated with the following equation:

$$\text{Oil yield (L ha}^{-1}) = \frac{\text{Essential oil (\%)} \times Y}{100} \quad (2)$$

where Y = fresh herbage yield (t ha^{-1}).

The chemical constituents of essential oil were determined in the second season only (Abd El-Wahab et al., 2016), using the Trace GC Ultra/Mass Spectrophotometer ISQ (Thermo Scientific) (GC/MS) apparatus to determine their main constituents (Charles and Simon, 1990). A citronellol/geraniol ratio (C: G) in essential oils was calculated according to the method described by Hamouda (2013).

2.6 Statistical analysis

In each season, the data were subjected to the analysis of variance in Randomized Complete Block Design (RCBD) by using SPSS 22.0 (SPSS, Inc., USA) package. Differences among means were compared for each trait using the least significant differences test (LSD) at a 5% level of probability (Steel et al., 1997). Correlations between EC and salinity were evaluated using Pearson correlation coefficients in Minitab version

18.3 (Minitab, Inc., State College, Pennsylvania, USA). All tests were declared significant at $P \leq 0.05$.

3 Results and Discussion

3.1 Effect of biochar

Application of biochar significantly ($P \leq 0.05$) affected *P. graveolens* plant height (cm), fresh herbage yield (t ha^{-1}), essential oil %, and oil yield (L ha^{-1}). Biochar application resulted in a significant increase in plant height, leaf area index, and fresh herbage yield of *P. graveolens* as compared with control and in reaching their maximum values at 10 t ha^{-1} (Fig. 2). An increase in biochar dose from zero to 10 t ha^{-1} caused significant increments in plant height (61.61%, 65.01%), leaf area index (32.85%, 33.49%), and fresh herbage yield (44.82%, 44.29%) in the first and second cut, respectively, whilst enhancement of biochar dose from 5 to 10 t ha^{-1} caused significant increments of 17.05% and 16.67% in plant height, 11.87% and 12.22% in leaf area index, 11.23% and 12.61% in fresh herbage yield in the first and second cut, respectively.

The application of biochar to *P. graveolens* plant significantly ($P \leq 0.05$) influenced oil % and oil yield ha^{-1} (Fig. 2D,E). The maximum essential oil % and oil yield were recorded in *P. graveolens* which received 10 t ha^{-1}. An increase of 50.0% in oil % after applying 10 t ha^{-1} biochar was noted in the first and second cuts, also the application of this rate resulted in a 117.23 and 116.43% increase in oil yield compared to the control. On the other hand, raising the biochar rate from 5 to 10 t ha^{-1} resulted in a 17.39% increase in oil % in the first and second cuts, accompanied by a significant increase in the oil yield. These results were in agreement with the works of Agegnehu et al. (2019) indicating that positive effects of biochar application on growth and oil yield of lemmon grass (*Cymbopogon citratuc* L.) with rates of 5 - 20 t ha^{-1}. Moreover, Mumivand et al. (2023) reported that adding 6% w/w biochar provided the highest growth, essential oil content, and yield in peppermint (*Mentha piperita* L.). Tavali (2022) investigated the effect of oak tree biochar application on the fresh herbage yield and essential oil % of marjoram (*Origanum majorana* L.), and they found that the highest fresh herbage yield and essential oil % were recorded when 40 tons biochar per hectare was added compared with the control.

Increasing growth and yield parameters with increasing biochar rates may be due to the increasing uptake of nutrients by *P. graveolens* and the availability of N, P, K, Cu, Fe, and Mn in soil (Abo-Ogiala, 2018; Calamai et al., 2019; Mancy and Sheta, 2021). Biological carbon sequestration, net biological, and soil carbon were also enhanced (Pandey et al., 2016; Agegnehu et al., 2019).

3.2 Effect of foliar application of compost tea

The main effects of the compost tea concentration, on electric conductivity EC) and salinity were significant ($P<0.05$). As the concentration of the compost tea was increased from 0.1% to 0.3%, EC increased linearly from 0.92 to 4.56 dS m^{-1} (Fig. 3a). EC is used to estimate the concentration of ionic substances in solutions including compost tea (Martínez-Suller et al., 2010; Abbey et al., 2012). According to Islam et al. (2016) and Vehniwal et al. (2020), EC values increase with an increase in compost:water ratio from 1:10 to 2.5. In the present study, the ionic substances in the compost tea will include various nutrients, salts and ionized macromolecules which were expected to increase with an increase in the concentration of the compost tea and higher EC value. In conformity with previous studies by Abbey et al. (2012) and Vehniwal et al. (2020), we found a strong linear relationship (R^2 = 0.9948) between EC and salinity (figure not presented). Consequently, the patterns of change in the compost tea salinity at the varied concentrations were similar to those found for EC (Fig. 3b).

Foliar application of compost tea had a highly significant ($P \leq 0.05$) effect on plant height, leaf area, fresh herbage yield, essential oil %, and oil yield. Foliar application of compost tea resulted in significant improvement in plant height, leaf area index, and fresh herbage yield of *P. graveolens* as compared with the control, and thus, they reached their maximum values at 0.1% (Fig. 4). Compared with the control, foliar application of compost tea at 0.1% caused significant increments in plant height (34.10%, 37.76%), leaf area index (29.68%, 32.76%), and fresh herbage yield (24.03%, 23.08%) in the first and second cut, respectively, whilst enhancement of compost tea concentration from 0.1 to 0.3% caused significant decrements of 16.39% and 18.18% in plant height (Fig. 4A), 12.67% and 13.84% in leaf area index (Fig. 4B), 17.44% and 18.39% in herbage yield (Fig. 4C) in the first and second cut, respectively. An increase in oil % accounting for 22.22% was noticed as compost tea was applied (0.1%). However, beyond this treatment, a decrease in oil % was reported where the medium and the higher applications of 0.2 and 0.3% had negative effects on the oil % in both cuts (Fig. 4D). Foliar application of 0.1% compost tea produced the highest essential oil yield. Compared with the control, increases in oil yield accounted for 51.59 and 50.43% due to compost tea application of 0.1% in the first and second cut, respectively (Fig. 4E). The dissimilar response of *P. graveolens* plants to different concentrations of compost tea may be due to differences in values of electrical conductivity and salinity.

These results confirm the effectiveness of compost tea in enhancing the growth and essential oil yield of some medicinal plants, as mentioned in very few

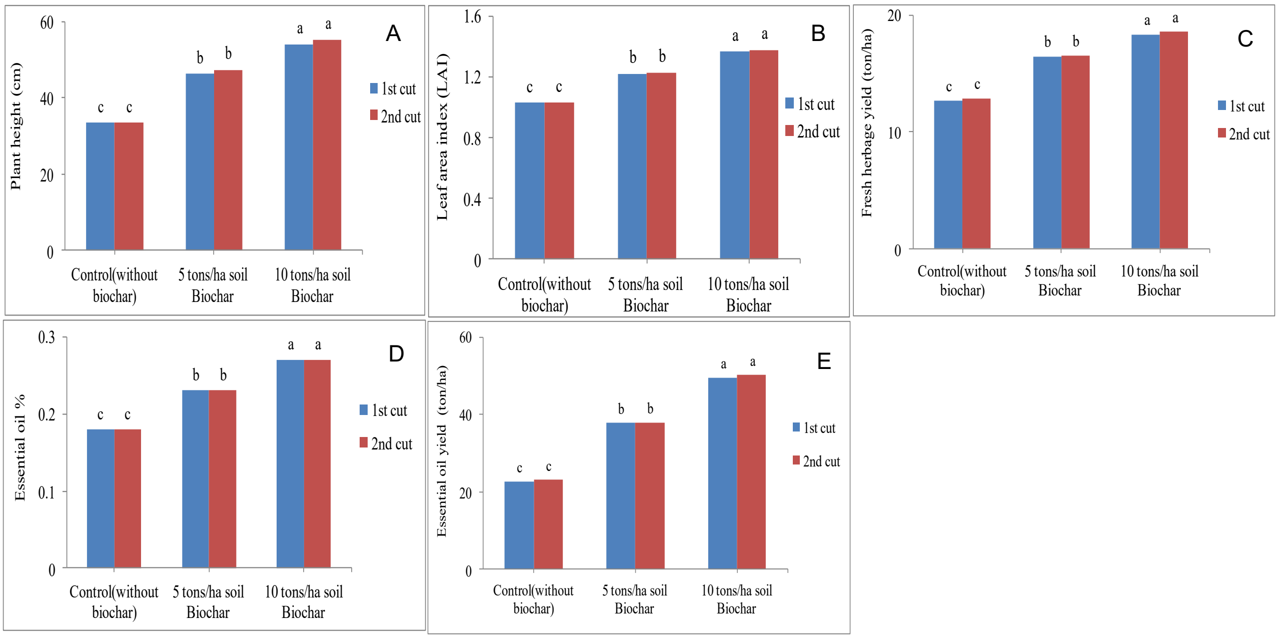

Figure 2. Effect of biochar on (A) plant height, (B) leaf area index, (C) fresh herbage yield (ton/ha), (D) essential oil %, and (E) essential oil yield of *P. graveolens* (Pooled data of 2019-2020 and 2020-2021 seasons). Values in the bar followed by the same letter(s) are not significantly different at a 5% level of probability

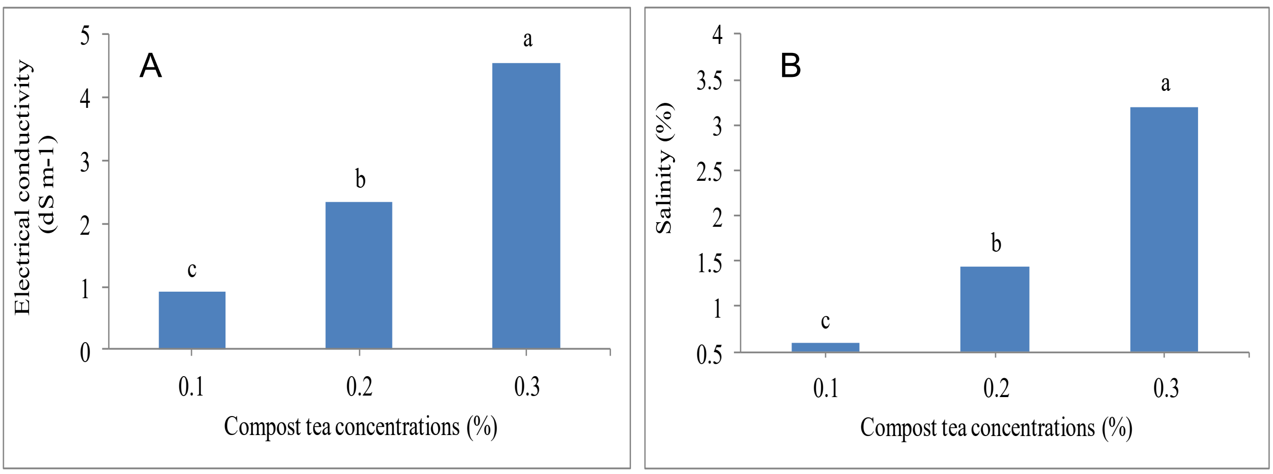

Figure 3. Effect of concentrations (0.1, 0.2 and 0.3%) on (A) electrical conductivity (dS m^{-1}) and (B) salinity (%) values of compost tea. Values in the bar followed by the same letter(s) are not significantly different at a 5% level of probability

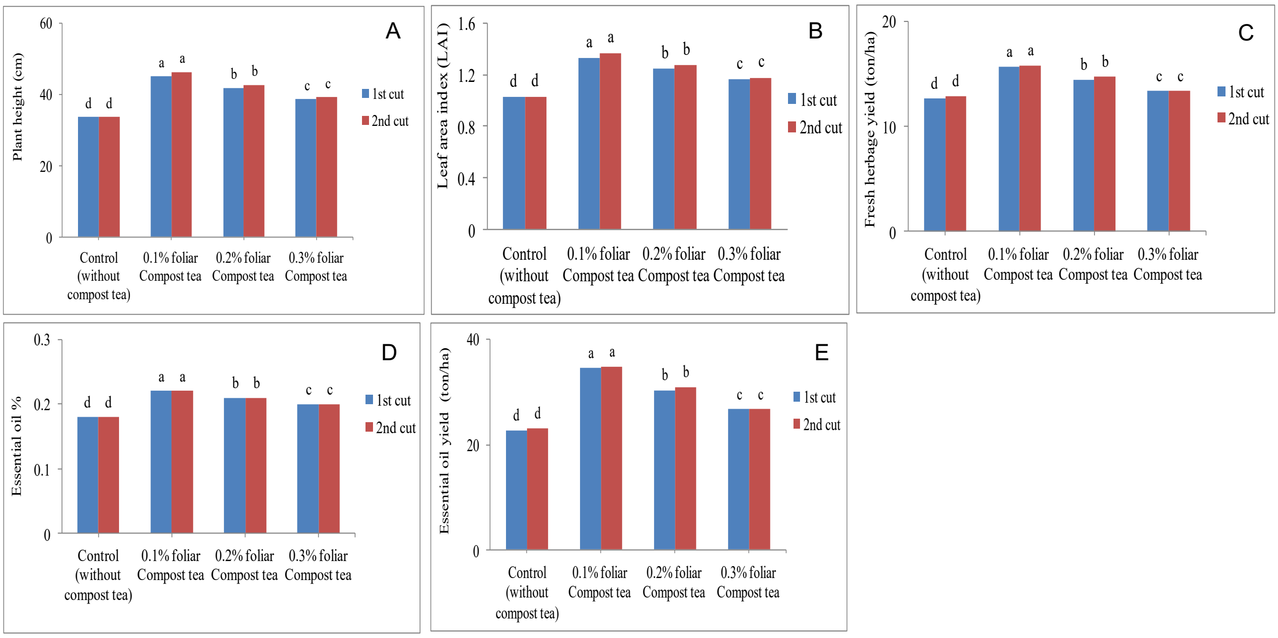

Figure 4. Effect of compost tea on (A) plant height, (B) leaf area index, (C) fresh herbage yield (t ha^{-1}), (D) essential oil %, and (E) essential oil yield of *P. graveolens* (Pooled data of 2019-2020 and 2020-2021 seasons). Values in the bar followed by the same letter(s) are not significantly different at a 5% level of probability

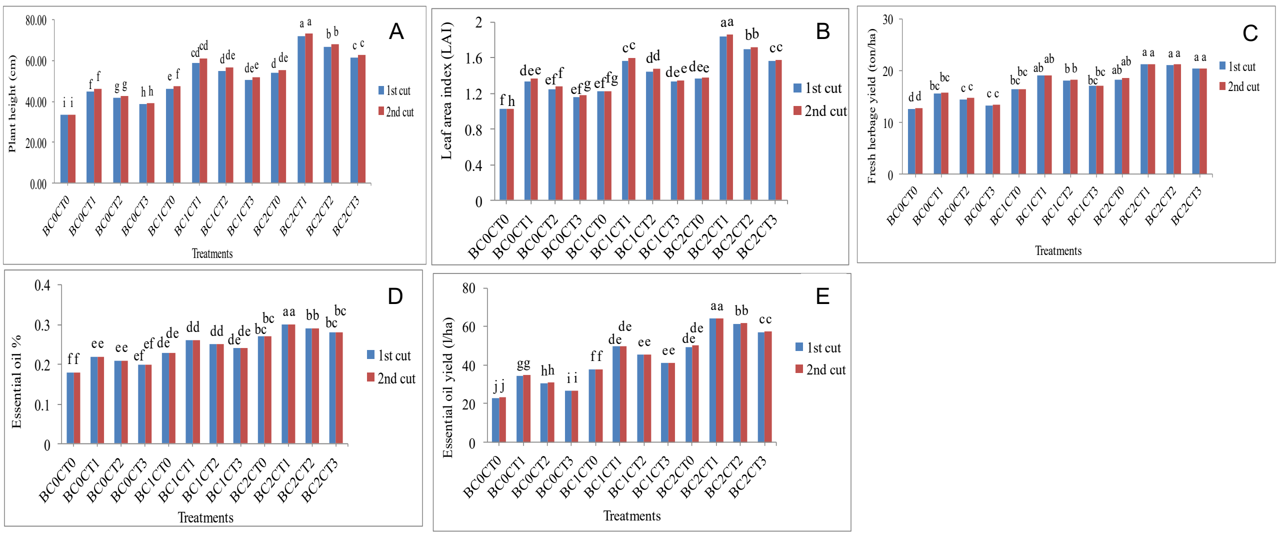

Figure 5. Effect of interaction between biochar and foliar application of compost tea on (A) plant height, (B) leaf area, (C) fresh herbage yield (t ha^{-1}), (D) essential oil %, and (E) essential oil yield of *P. graveolens* (Pooled data of 2019-2020 and 2020-2021 seasons). BC0, without biochar; BC1, 5 t ha^{-1} biochar ; BC2, 10 t ha^{-1} biochar; CT0, zero compost tea; CT1, 0.1% compost tea; CT2, 0.2 % compost tea; CT3, 0.3% compost tea. Values in the column followed by the same letter(s) are not significantly different at a 5% level of probability

Table 4. Effect of biochar or/and compost tea on essential oils composition (citronellol, geraniol, Citronellyl formate, isomenthone and linalool) of P. graveolens plants in the second season (2020-2021)

Treatments	Citronellol		Geraniol		Citronellyl formate		Isomenthone		Linalool	
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
BC0CT0	18.9 d	19.0 d	11.5 c	11.6 c	1.6 c	1.6 c	1.6 c	1.6 c	1.1 b	1.1 b
BC0CT1	20.2 d	20.3 d	13.9 c	13.9 c	3.3 b	3.5 b	4.0 b	4.1 b	1.2 b	1.2 b
BC0CT2	19.8 d	20.0 d	13.4 c	13.4 c	1.8 c	1.8 c	3.9 b	3.9 b	1.2 b	1.2 b
BC0CT3	19.1 d	19.9 d	11.6 c	11.6 c	1.7 c	1.7 c	2.7 c	2.7 c	1.2 b	1.2 b
BC1CT0	20.2 d	20.5 d	13.9 c	14.0 c	3.5 b	3.7 b	4.3 b	4.3 b	1.3 b	1.5 b
BC1CT1	25.5 c	25.8 c	17.4 b	17.4 b	6.1 a	6.2 a	6.3 a	6.5 a	1.5 b	1.8 b
BC1CT2	20.9 d	21.5 d	17.0 b	17.1 b	3.8 b	3.9 b	4.5 b	4.5 b	1.4 b	1.5 b
BC1CT3	20.4 c	20.6 c	16.9 b	16.9 b	3.7 b	3.8 b	4.3 b	4.4 b	1.4 b	1.4 b
BC2CT0	24.7 c	24.9 c	17.4 b	17.4 b	6.1 a	6.1 a	4.5 b	4.7 b	1.5 b	1.5 b
BC2CT1	33.5 a	33.5 a	24.3 a	24.3 a	6.7 a	6.7 a	7.2 a	7.2 a	3.0 a	3.0 a
BC2CT2	32.2 a	32.8 a	18.3 b	18.5 b	6.3 a	6.6 a	7.1 a	7.1 a	3.0 a	3.0 a
BC2CT3	28.4 b	28.7 b	17.7 b	17.7 b	6.2 a	6.3 a	6.5 a	6.6 a	1.9 b	2.0 b

reports. One of the studies reported that exogenously applied compost tea promoted growth parameters, such as plant height and essential oil % and oil yield of fennel (*Foeniculum vulgare* Mill) (Mohamed et al., 2022), herb fresh weight per plant and essential oil content and yield of dragonhead (*Dracocephalum moldavica* L) (Ahl and Khalid, 2010). A similar response was proposed by Ahmed and Zahwan (2022) while working with marjoram (*Origanum majorana* L.) since plant height, leaf area index, and essential oil % were improved by compost tea application at 100 g L^{-1}.

The superiority of compost tea fertilization in the growth parameters of *P. graveolens* plants is attributed to the role of spraying with compost tea as it is rich in nitrogen and phosphorous, which are included in the synthesis of amino and nucleic acids and proteins and processing plants with growth stimulants such as auxins, gibberellins, cytokinins, vitamins and organic acid (Kim et al., 2015) which encourages the process of cell division and elongation and activates microorganisms that secrete some substances similar to plant hormones and as a result contribute to an increase in cell division and an increase in their size, which results in an increase in vegetative growth parameters (Al-Omrani, 2010). Moreover, compost tea was significantly superior in essential oil yield. This can be due to the CT that provided the plant with nutrient requirements and increased the efficiency of vital processes, especially photosynthesis, and respiration. Thus, increasing the production of secondary compounds, including essential oil (Ahl and Khalid, 2010).

3.3 Interaction between biochar and foliar application of compost tea

Concerning the interaction between biochar and foliar application of compost tea treatments, it was significant, in both cuts, as indicated in (Fig. 5). All interacting treatments gave significantly ($P \leq 0.05$) best values of plant height, leaf area index, and fresh herbage yield in addition to essential oil % and oil yield, in comparison with the control treatment. Among interacting treatments, the plants receiving biochar at 10 t ha^{-1} in combination with compost tea 0.1% could be the best choice. The numerical increase in the above-mentioned parameters, in comparison with that of control treatment, reached 115.30, 79.59, 68.85, 66.67 and 181.42%, in the first cut and 118.66, 80.04, 65.81, 66.67 and 176.35% in the second cuts for the tested parameters, respectively. Gumelar and Seo (2021) studied the effect of three doses of biochar (0, 5, and 10 t ha^{-1}) and three levels of compost tea (0, 50, and 150 mL/plant) on the growth and yield of peanut (*Arachis hypogaea* L.) and they found that the combined application of biochar and compost tea had a synergistic effect on the growth and yield than the application of each treatment alone. The overall best growth and yield of peanut were achieved in biochar at 10 t ha^{-1} + compost tea at 150 mL/plant treatment. Similar results were obtained by Manga et al. (2023) on okra (*Abelmoschus esculentus* L. Moench).

3.4 Essential oil composition

The GC–MS analysis (Table 4) of essential oil showed that the five most represented chemical oil components were: citronellol (19.0 - 33.5%), geraniol (11.5 - 24.3%), Citronellyl formate (1.6 - 6.7%), isomenthone (1.6 - 7.2 %) and linalool (1.1 - 3.0%). These results are in line with the Calamai et al. (2019) findings on *P. graveolens*, which proved that citronellol and geraniol were the most abundant volatile compounds. The interaction effect of compost tea and biochar application on essential oil composition was significant ($P \leq 0.05$). The maximum content of citronellol (33.5%) and geraniol (24.3%) was recorded at 10 t ha^{-1} biochar with 0.1% compost tea. The lowest content of citronellol (18.9%) and geraniol (11.5%) was obtained from the control.

Table 5. Effect of biochar or/and compost tea on quality of essential oils (citronellol and geraniol ratio C/G) of *P. graveolens* plants in the second season (2020-2021)

Treatments	C/G Ratio	
	1st cut	2nd cut
BC0CT0	1.64 a	1.64 a
BC0CT1	1.45 ab	1.46 ab
BC0CT2	1.48 ab	1.49 ab
BC0CT3	1.65 a	1.72 a
BC1CT0	1.45 ab	1.46 ab
BC1CT1	1.47 ab	1.48 ab
BC1CT2	1.23 b	1.26 b
BC1CT3	1.21 b	1.22 b
BC2CT0	1.42 ab	1.43 ab
BC2CT1	1.38 ab	1.38 ab
BC2CT2	1.76 a	1.77 a
BC2CT3	1.60 a	1.62 a

3.5 Essential oil quality

The oil quality in geranium is commercially determined by the citronellol and geraniol ratio (C/G). The geranium oil possesses C/G ratio equivalent to 1 which is considered as the oil with best odor quality and hence, preferred by industry (Saxena et al., 2008; Palchetti et al., 2019). In this research, the application of biochar and compost tea slightly influenced the oil quality of *P. graveolens*, leaving their chemical characteristics within the range (C/G ratio of 1.21 - 1.77) that is recommended by the international standard trade for high-quality oils (Table 5).

4 Conclusion

The best treatment recommended would be 10 t ha^{-1} biochar + 0.1% compost tea and followed by 10 t ha^{-1} biochar + 0.2% compost tea in order to achieve the highest yield and excellent quality of essential oil under these experimental conditions. Moreover, Future investigation is required to determine the optimum doses of biochar and compost tea.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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