# The effect of organic material type and foliar application of plant extracts on the vegetative growth characteristics and volatile oil yield of rosemary plant

**Raed S. H Sultani *, Sulaiman A M Al-Dhalimi**

[1]Department of Horticulture, Faculty of Agriculture, University of Kufa, Najaf, Iraq.
*Corresponding author e-mail: raeds.sultani@student.uokufa.edu.iq
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**Abstract**
A factorial field experiment was conducted during the 2024-2025 growing season at the research station of the College of Agriculture, University of Kufa, under green shade cloth (60% light transmission) to investigate the effects of organic materials and foliar plant extracts on vegetative growth and volatile oil yield of rosemary (*Rosmarinus officinalis* L.). The experiment followed a randomized complete block design with three replications. Two factors were examined: organic material type [wheat residues (O1), mushroom residues (O2), and control (O0)] applied at 5 tons $ha^{-1}$, and foliar plant extracts [moringa extract (E1), hibiscus extract (E2), and control (E0)] applied at 10 ml $L^{-1}$. Results demonstrated that wheat residues significantly increased leaf number (3,505 leaves $plant^{-1}$), shoot dry weight (40.54 g), and branch number (44.59 branches $plant^{-1}$) compared to other treatments. Hibiscus extract enhanced plant height (42.11 cm) and branch number (45.70 branches $plant^{-1}$), while moringa extract maximized leaf number (3,233.3 leaves $plant^{-1}$). For essential oil characteristics, mushroom residues produced superior oil yield (1.26%) and refractive index (1.746 nm). The interaction O2×E0 achieved the highest oil yield (1.41%), indicating significant synergistic effects. These findings suggest that strategic selection of organic materials combined with appropriate foliar extracts can substantially enhance rosemary production systems for commercial cultivation
**Keywords:** Organic material, Volatile Oil, Rosemary Plant

## Introduction

Rosemary (*Rosmarinus officinalis* L.) is a Mediterranean aromatic herb of the Lamiaceae family and it is extensively cultivated for its essential oil rich in bioactive compounds including α-pinene, eucalyptol, and verbenone [1]. The increasing global demand for natural products has intensified research efforts to optimize sustainable cultivation practices while enhancing essential oil yield and quality [2]. Modern agricultural systems emphasize integrated approaches combining organic fertilization with biostimulant applications to improve crop productivity and environmental sustainability [3].

Organic fertilizers significantly influence essential oil composition and yield through enhanced nutrient availability and improved soil biological activity [4]. Wheat residues provide balanced nutrient release patterns due to their optimal carbon-to-nitrogen ratio, supporting sustained plant growth throughout the growing season [5]. Mushroom compost, characterized by balanced micronutrient content and excellent physical properties, enhances secondary metabolite synthesis in aromatic plants [6]. Research demonstrates that organic amendments improve soil microbial diversity, leading to enhanced nutrient cycling and plant performance [7].

Plant-based biostimulants represent innovative tools for sustainable agriculture, offering natural alternatives to synthetic growth regulators [8]. *Moringa oleifera* leaf extract contains growth-promoting compounds including cytokinins, auxins, and essential nutrients that enhance plant physiological processes [9]. Recent studies confirm moringa extract effectiveness in improving growth parameters and essential oil content in aromatic plants through enhanced photosynthetic activity and nutrient uptake [10]. *Hibiscus sabdariffa* extract, rich in phenolic compounds and natural antioxidants, demonstrates potential as foliar biostimulant due to its ability to enhance cellular metabolism [11].

The integration of organic fertilization with foliar biostimulant applications offers synergistic benefits for aromatic plant cultivation [12]. However, limited research exists on the interactive effects of different organic residue types combined with plant extract applications on rosemary growth and essential oil characteristics. Previous studies indicate that combining organic and inorganic nutrient sources can increase herbage yield by 66.1% and oil yield by 54.9% in rosemary [13], yet the optimal combinations remain undefined.

This study aimed to evaluate the individual and interactive effects of organic material type (wheat vs. mushroom residues) and foliar plant extracts (moringa vs. hibiscus) on vegetative growth parameters and essential oil yield and quality of rosemary under controlled greenhouse conditions.

Despite the growing demand for sustainable rosemary cultivation practices, significant knowledge gaps persist regarding the optimal combinations of organic amendments and foliar biostimulants for maximizing both vegetative growth and essential oil production. While previous studies have examined individual effects of organic fertilizers or plant extracts separately, the interactive effects of different organic residue types (wheat vs. mushroom) combined with specific plant extract applications (moringa vs. hibiscus) remain poorly understood. Furthermore, the physiological mechanisms underlying differential responses in vegetative parameters versus essential oil characteristics have not been adequately elucidated. This research addresses these critical gaps by investigating: (1) the comparative efficacy of wheat and mushroom residues as soil amendments, (2) the distinct roles of moringa and hibiscus extracts as foliar biostimulants, and (3) the synergistic or antagonistic interactions between soil amendments and foliar applications in influencing rosemary growth dynamics and essential oil yield and quality. Resolving these questions is essential for developing evidence-based recommendations for commercial rosemary production systems that optimize resource use efficiency while maintaining environmental sustainability.

## Materials and Methods

### Experimental Site and Conditions

The experiment was conducted during the 2024-2025 growing season at the research station of the College of Agriculture, University of Kufa, in a greenhouse covered with green shade cloth on rosemary plants. The study was carried out under the influence of two factors including:

**Factor A (Organic Fertilizer):** This included two types of compost: the first type (O1) compost from wheat crop residues, prepared by the organic agriculture project in Al-Abbasiya district affiliated to Najaf city center, and the second type (O2) compost from edible mushroom residues from the mushroom farm project located in Afak district affiliated to Diwaniyah city center, in addition to the control treatment (O0) without organic fertilizers.

**Factor B (Plant Extracts):** This included two types of plant extracts: the first type (E1) was moringa leaf extract while and the second type (E2) hibiscus leaf extract, in addition to the control treatment (E0) spraying with distilled water only.

### Site Preparation and Experimental Setup

The cultivation area was prepared under a greenhouse covered with 60% green shade cloth with an area of 30 × 9 m. Soil cultivation was carried out using machinery at a depth of 30 cm to ensure soil softening and breaking up to eliminate harmful weeds. After that, soil sterilization was performed by A formalin solution (2–5%) was mixed thoroughly with the soil to a depth of 20–30 cm, after which the soil was covered with plastic sheets for 10–15 days to ensure effective sterilization.

Ensure the sterilization process and to secure plants from damage caused by the sterilizing material. The area was then divided into plots in the form of raised beds at a height of 35 cm, with 27 plots of 2 × 2 m area for each plot, leaving a buffer distance of 1.5 m between plots (raised beds) to ensure no water leakage from one plot to another and to facilitate service operations.

After that, the surfaces of the plots were accurately leveled and the plots were defined with shoulders at a height of 20 cm to ensure no leakage of irrigation water and its even distribution in the plot. The experimental units were applied to the experimental plots, then organic matter was added at a rate of 5 tons $ha^{-1}$ by mixing it with soil at a depth of 15 cm. Wheat residue compost and mushroom residue compost were distributed according to quantity on the units under study.

The experimental unit included three replications, each replication comprising three plots with 30 plants per plot, where the plant density reached 75,000 plants $ha^{-1}$. The total number of experimental plants was 810 plants.

### Experimental Design

A factorial experiment design was used, implemented in a split-plot design according to the Randomized Complete Block Design (R.C.B.D) to study two factors: the first factor is the effect of two types of organic matter in addition to the control (without organic fertilizers), and the second factor is two types of plant extracts in addition to the control treatment to determine the effect of these factors on vegetative characteristics and volatile oil yield and quality.

Extract Preparation and Application

**Table (1):** Chemical Composition of Organic Fertilizers and Plant Extracts

| Material | N (%) | P (%) | K (%) | Organic Matter (%) | pH |
|---|---|---|---|---|---|
| **Wheat Residue** | 1.8 | 0.6 | 1.2 | 45.3 | 7.2 |
| **Mushroom Residue** | 2.1 | 0.8 | 1.5 | 52.7 | 6.8 |
| **Moringa Extract** | 0.58 | 0.12 | 1.85 | Zeatin + IAA | 6.5 |
| **Hibiscus Extract** | 0.45 | 0.08 | 1.62 | Phenolics + Anthocyanins | 5.8 |

Moringa Leaf Extract Preparation: Fresh moringa leaves (100 g) were collected from mature trees, washed thoroughly with distilled water, and blended with 1000 ml of distilled water using a laboratory blender. The mixture was filtered through cheesecloth and the filtrate was diluted to achieve the desired concentration of 10 ml $L^{-1}$ [14,15].

Hibiscus Leaf Extract Preparation: Fresh hibiscus leaves (100 g) were prepared using the same methodology as moringa extract. The leaves were blended with distilled water, filtered, and diluted to 10 ml $L^{-1}$ concentration [14,15].

Both extracts were prepared before each application to maintain bioactivity. Foliar applications were performed early morning (7:00-9:00 AM) to minimize evaporation and maximize absorption. A surfactant (Tween-20 at 0.1% v/v) was added to enhance leaf penetration. Applications were made twice during the growing season: first application 30 days after transplanting and second application 60 days after transplanting.

Data Collection

Vegetative Growth Parameters:

- Plant height (cm): Measured from soil surface to the highest growing point
- Number of leaves per plant: Total count of fully developed leaves
- Leaf dry matter percentage (%): Determined by oven-drying at 70°C until constant weight
- Number of branches per plant: Count of secondary shoots longer than 5 cm
- Shoot dry weight (g): Total above-ground biomass after drying

Essential Oil Analysis:

- Essential oil yield (%): Determined by steam distillation using Clevenger apparatus
- Oil specific density (mg $\mu L^{-1}$): Measured using pycnometer method
- Oil specific weight (g $cm^{-3}$): Calculated from density measurements
- Oil refractive index (nm): Determined using Abbe refractometer at 20°C
- Oil pH: Measured using digital pH meter

All measurements were conducted at the end of the growing season (120 days after transplanting). Essential oil extraction was performed on fresh leaf samples (100 g) using steam distillation for 3 hours. The extracted oils were analyzed immediately for physical and chemical characteristics using standard analytical procedures [16].

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SAS statistical software (version 9.4). Treatment means were compared using Least Significant Difference (LSD) test at P ≤ 0.05 level of significance. The factorial design allowed for evaluation of main effects and interactions between organic materials and foliar extract treatments.

## Results and Discussion

### Vegetative Growth Characteristics

Analysis of variance revealed significant main effects and interactions for all vegetative parameters studied. Wheat residues (O1) demonstrated superior performance in leaf production (3,505 leaves plant$^{-1}$), shoot biomass accumulation (40.54 g), and branching development (44.59 branches plant$^{-1}$) compared to mushroom residues (O2: 2,677.8 leaves plant$^{-1}$, 36.50 g, and 40.00 branches plant$^{-1}$, respectively). The control treatment (O0) exhibited the greatest plant height (41.26 cm), differing significantly from organic treatments. These results support previous findings demonstrating enhanced nutrient availability from wheat-based amendments through optimal decomposition rates and balanced nutrient release [17]. The superior vegetative response to wheat residues reflects improved soil biological activity and sustained nitrogen availability throughout the growing period [18].

Foliar extract applications significantly influenced plant morphology and development patterns. Hibiscus extract (E2) maximized plant height (42.11 cm) and branch development (45.70 branches plant$^{-1}$), with statistical significance confirmed by $LSD_{0.05}$ values of 0.6433 and 3.2423, respectively. Moringa extract (E1) enhanced leaf production (3,233.3 leaves plant$^{-1}$), while the control treatment (E0) promoted shoot biomass accumulation (38.20 g). These responses align with research demonstrating biostimulant effects of plant extracts through natural growth regulators and bioactive compounds [19]. The phenolic compounds and growth-promoting substances in hibiscus extract particularly enhance apical meristem activity and lateral bud development [20].

**Table (2):** Effect of organic materials, foliar extracts and their interaction on vegetative growth characteristics of rosemary

| Treatment | Plant Height (cm) | Leaf Number (leaves plant$^{-1}$) | Leaf Dry Weight (%) | Branch Number (branches plant$^{-1}$) | Shoot Dry Weight (g) |
|---|---|---|---|---|---|
| Organic Material | | | | | |
| O0 (Control) | 41.259 | 3259.3 | 46.418 | 39.370 | 35.741 |
| O1 (Wheat residues) | 38.556 | 3505.0 | 46.566 | 44.593 | 40.5438 |
| O2 (Mushroom residues) | 38.852 | 2677.8 | 47.456 | 40.000 | 36.495 |

| | | | | | |
|---|---|---|---|---|---|
| LSD (0.05) | 0.6433 | 289 | 1.5474 | 3.2423 | 2.6924 |
| Foliar Extract | | | | | |
| E0 (Control) | 35.370 | 2924.4 | 47.733 | 38.963 | 38.198 |
| E1 (Moringa) | 41.185 | 3233.3 | 47.261 | 39.296 | 35.085 |
| E2 (Hibiscus) | 42.111 | 3284.3 | 47.261 | 45.704 | 39.491 |
| LSD (0.05) | 0.6433 | 289 | 1.5474 | 3.2423 | 2.6924 |
| Interaction (O×E) | | | | | |
| O0×E0 | 40.000 | 2173.3 | 50.651 | 40.000 | 33.390 |
| O0×E1 | 38.222 | 4163.9 | 49.882 | 40.889 | 30.614 |
| O0×E2 | 37.000 | 2055.6 | 50.870 | 46.778 | 39.091 |
| O1×E0 | 37.889 | 3544.4 | 44.5998 | 41.222 | 40.417 |
| O1×E1 | 42.222 | 4333.3 | 44.118 | 47.111 | 39.737 |
| O1×E2 | 43.444 | 2033.3 | 44.944 | 44.778 | 36.671 |
| O2×E0 | 33.333 | 3055.6 | 52.590 | 35.667 | 40.776 |
| O2×E1 | 43.111 | 4163.9 | 50.496 | 38.222 | 34.905 |
| O2×E2 | 46.000 | 3622.2 | 52.590 | 42.333 | 42.710 |
| LSD (0.05) | 1.1142 | 500.57 | 2.6802 | 5.6159 | 4.6634 |

Interaction analysis revealed significant synergistic effects between organic materials and foliar treatments. The combination O1×E1 maximized leaf production (4,333.3 leaves plant$^{-1}$) and branching (47.11 branches plant$^{-1}$), while O2×E2 achieved optimal plant height (46.00 cm). Treatment O1×E0 produced the highest shoot biomass (40.42 g). These interactions demonstrate complementary mechanisms whereby organic amendments provide sustained nutrition while plant extracts enhance metabolic processes and cellular development [21]. The observed synergies support integrated management approaches for optimizing aromatic plant production systems.

Essential Oil Characteristics (Table 2)

Essential oil analysis demonstrated significant treatment effects on yield and quality parameters. Mushroom residues (O2) enhanced oil yield (1.26%) and refractive index (1.746 nm) while reducing oil pH (5.89) compared to wheat residues (O1: 1.22% yield, 1.706 refractive index). The control treatment (O0) achieved intermediate oil yield (1.24%) but exhibited superior oil density (750.85 mg µL$^{-1}$) and specific weight (1.012 g cm$^{-3}$). These findings confirm that mushroom-based amendments enhance essential oil biosynthesis through improved secondary metabolite pathways and favorable micronutrient availability for terpene synthesis [22]. The enhanced oil quality reflects the balanced mineral composition of mushroom compost, particularly trace elements essential for enzymatic processes in oil production [23].

Foliar extract applications produced distinct effects on oil characteristics. The control treatment (E0) maximized oil yield (1.29%), while moringa extract (E1) optimized oil density (743.37 mg µL⁻¹) and specific weight (0.989 g cm⁻³). Hibiscus extract (E2) produced intermediate values across parameters (1.23% oil yield, 732.37 mg µL⁻¹ density). The superior oil yield under control conditions suggests that excessive foliar applications may redirect plant metabolism toward vegetative development rather than oil accumulation [24]. However, moringa extract significantly enhanced oil quality characteristics, indicating improved composition and bioactive compound concentration [25].

Interaction analysis revealed pronounced synergistic responses between treatments. The combination O2×E0 achieved maximum oil yield (1.41%), while O0×E1 produced optimal oil density (762.56 mg µL⁻¹). Treatment O2×E1 exhibited the highest refractive index (1.761 nm), indicating superior oil purity and concentration. Conversely, O0×E1 demonstrated the lowest oil yield (1.05%), suggesting potential antagonistic interactions between control soil conditions and moringa applications. These patterns confirm that mushroom amendments create favorable soil environments for essential oil synthesis when combined with appropriate foliar management [26]. The significant $LSD_{0.05}$ value (0.001383) for interactions validates the statistical reliability of these synergistic effects, supporting integrated approaches for optimizing aromatic plant production systems.

**Table (3):** Effect of organic materials, foliar extracts and their interaction on essential oil characteristics of rosemary

| Treatment | Oil Yield (%) | Oil Density (mg µL⁻¹) | Oil Specific Weight (g cm⁻³) | Oil Refractive Index (nm) | Oil pH |
|---|---|---|---|---|---|
| Organic Material | | | | | |
| O0 (Control) | 1.241 | 750.852 | 1.0115 | 1.7274 | 6.393 |
| O1 (Wheat residues) | 1.222 | 724.519 | 0.9487 | 1.7059 | 6.100 |
| O2 (Mushroom residues) | 1.255 | 716.815 | 0.9487 | 1.7456 | 5.885 |
| LSD (0.05) | 0.0004611 | 17653 | 0.0472 | 0.0151 | 0.1734 |
| Foliar Extract | | | | | |
| E0 (Control) | 1.292 | 716.444 | 0.9659 | 1.7226 | 6.067 |
| E1 (Moringa) | 1.195 | 743.370 | 0.9893 | 1.7319 | 6.130 |
| E2 (Hibiscus) | 1.232 | 732.370 | 0.9698 | 1.7244 | 6.182 |
| LSD (0.05) | 0.0004611 | 17653 | 0.0472 | 0.0151 | 0.1734 |
| Interaction (O×E) | | | | | |
| O0×E0 | 1.334 | 733.667 | 1.014 | 1.731 | 6.477 |
| O0×E1 | 1.051 | 762.556 | 1.014 | 1.720 | 6.522 |
| O0×E2 | 1.339 | 756.333 | 1.005 | 1.731 | 6.177 |

| | | | | | |
|---|---|---|---|---|---|
| O1×E0 | 1.129 | 710.667 | 0.944 | 1.692 | 6.033 |
| O1×E1 | 1.322 | 741.222 | 0.986 | 1.714 | 6.133 |
| O1×E2 | 1.215 | 721.667 | 0.915 | 1.711 | 6.133 |
| O2×E0 | 1.413 | 705.000 | 0.938 | 1.744 | 5.688 |
| O2×E1 | 1.212 | 762.333 | 0.967 | 1.761 | 5.733 |
| O2×E2 | 1.141 | 719.111 | 0.988 | 1.731 | 6.233 |
| LSD (0.05) | 0.001383 | 52960 | 0.1416 | 0.0452 | 0.5202 |

This study provides comprehensive evidence for the effectiveness of integrated organic fertilization and foliar biostimulant applications in enhancing rosemary production systems. The research demonstrates that wheat residues significantly outperformed mushroom residues in promoting vegetative growth parameters, achieving superior leaf production (3,505 vs. 2,677.8 leaves plant$^{-1}$), shoot biomass accumulation (40.54 vs. 36.50 g), and branching development (44.59 vs. 40.00 branches plant$^{-1}$). These findings support the utilization of wheat-based composts as sustainable soil amendments for aromatic plant cultivation [27].

Foliar applications of plant extracts demonstrated distinct and beneficial effects on rosemary growth and development. Hibiscus extract maximized plant height (42.11 cm) and branch development (45.70 branches plant$^{-1}$), while moringa extract enhanced leaf production (3,233.3 leaves plant$^{-1}$). These results confirm the biostimulant potential of plant-derived extracts in optimizing morphological development through natural growth-promoting compounds [28].

Essential oil production responded differentially to treatment combinations, with mushroom residues enhancing oil yield (1.26%) and quality characteristics, while maintaining optimal refractive index values (1.746 nm). The interaction O2×E0 achieved the highest oil yield (1.41%), demonstrating significant synergistic effects between organic amendments and foliar management strategies. These findings align with research emphasizing the importance of secondary metabolite enhancement through integrated nutrient management approaches [29].

The statistical significance of treatment interactions ($LSD_{0.05}$ = 0.001383 for oil yield) validates the importance of optimizing both soil amendments and foliar applications simultaneously. The study confirms that sustainable rosemary production systems can be developed through strategic combination of organic materials with biostimulant applications, offering environmentally sound alternatives to conventional fertilization practices [30].

**Practical Applications**

Based on the experimental findings, rosemary producers should consider implementing wheat residue compost at 5 tons ha$^{-1}$ as the primary organic amendment for maximizing vegetative growth and biomass production. This recommendation aligns with sustainable agriculture principles emphasizing the utilization of agricultural by-products for crop production [31]. The application should be integrated into soil preparation protocols approximately 2-3 weeks before transplanting to ensure optimal decomposition and nutrient availability.

For essential oil production systems, mushroom residue compost combined with minimal foliar applications (control treatment) provides optimal oil yield enhancement. This strategy supports commercial operations focused on maximizing oil extraction efficiency while maintaining sustainable production practices [32]. Producers targeting essential oil markets should prioritize this combination for achieving superior oil quality and concentration.

Future Research Directions

Further investigation is warranted to evaluate the long-term effects of repeated organic amendment applications on soil health indicators and plant performance across multiple growing seasons. Research should examine the cumulative impacts of wheat and mushroom residue applications on soil microbial communities, nutrient cycling processes, and plant-soil interactions [33]. Such studies would provide essential information for developing sustainable crop rotation and soil management strategies.

The optimization of plant extract concentrations and application timing requires additional research to maximize biostimulant effectiveness while minimizing input costs. Future studies should investigate concentration-response relationships for moringa and hibiscus extracts across different growth stages and environmental conditions [34]. This research would enable the development of precision application protocols for commercial implementation.

Investigating the biochemical mechanisms underlying the observed synergistic interactions between organic amendments and plant extracts represents a priority research area. Studies employing metabolomics and transcriptomics approaches could elucidate the molecular pathways responsible for enhanced growth and essential oil production [35]. Such mechanistic understanding would facilitate the development of targeted biostimulant formulations for aromatic plant production.

**Economic and Environmental Considerations**

Economic analysis of the recommended production systems should be conducted to evaluate cost-benefit ratios and identify optimal input combinations for different market scenarios. Research should assess the economic viability of organic amendment applications relative to conventional fertilization strategies [36]. This analysis would support decision-making processes for commercial producers transitioning to sustainable production systems.

Environmental impact assessments of the recommended practices should be performed to quantify benefits related to carbon sequestration, nutrient retention, and biodiversity conservation. Studies should evaluate the environmental footprint of organic amendment production and application compared to synthetic fertilizer systems [37]. Such assessments would support policy development and certification programs for sustainable aromatic plant production.

The scalability of laboratory and greenhouse findings to field conditions requires validation through multi-location field trials across diverse agro-ecological zones. Research should examine the performance of recommended practices under varying climatic conditions, soil types, and management systems [38]. This validation would ensure the broad applicability of research findings and support technology transfer to farming communities.

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