Kocabaş Oğuz I and Vuran FA (2026)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 54, Issue 1, Article number 14899
https://doi.org/10.15835/nbha54114899
Research Article

Effects of organo-mineral fertilizers on lavender production in low fertility soils

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Abstract

Lavender (*Lavandula angustifolia* Mill.) is a valuable medicinal and aromatic plant widely cultivated in semi-arid Mediterranean regions for its essential oil. However, under rainfed conditions, low soil fertility can adversely affect plant growth and oil quality. This study evaluated the effects of organo-mineral and mineral fertilization on yield and essential oil composition of the 'Raya' cultivar grown in calcareous, nutrient-poor soils of Antalya, Türkiye. For the field experiment, plants were planted in October 2020. Fertilizer applications and harvesting were carried out in 2022 and 2023. The field experiments were conducted using a randomized complete block design with four replications and four treatments: phosphorus-based organo-mineral (OM-NP), potassium-based organo-mineral (OM-NK), mineral nitrogen (M-N), and control (unfertilized). Fertilization significantly increased fresh and dry herb yields in both experimental years, with the highest biomass obtained from OM-NK plots. OM-NP resulted in the highest essential oil content in 2022 (6.43%), whereas in 2023 the highest value was recorded under OM-NK fertilization (5.15%). The major constituents were linalool (34.7-61.7%) and linalyl acetate (7.3-21.8%), which were not significantly influenced by fertilization. In contrast, stress-related compounds such as limonene, 1,8-cineole, and camphor were more abundant in control plants. Under low soil fertility conditions, organo-mineral fertilization resulted in marked increases in lavender yield while having only a limited effect on the essential oil composition.

Keywords: calcareous soils; essential oil content; *Lamiaceae*; rainfed agriculture; secondary metabolites

Introduction

Lavender (*Lavandula* spp.), a member of the *Lamiaceae* family, comprises nearly 39 species and 79 intraspecific taxa and hybrids worldwide (Héral *et al*., 2021). With its high aromatic and medicinal value, lavender has long been utilized as a raw material in industries such as cosmetics, perfumery, soap, and ointments. Its essential oil is particularly valued for its antibacterial, anti-inflammatory, and antioxidant properties, which

Received: 23 Nov 2025. Received in revised form: 08 Feb 2026. Accepted: 12 Feb 2026. Published online: 20 Mar 2026.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

makes it an important natural product for the health, cosmetic, and food industries (Fahimnia *et al*., 2024; Kayiran *et al*., 2025).

Among the species of economic and aromatic importance, *Lavandula angustifolia* Miller is distinguished by its essential oil composition, which contains high proportions of oxygenated monoterpenes, particularly linalool and linalyl acetate, as well as lavandulyl acetate and α-terpineol. Due to its low camphor content, high essential oil yield, and pleasant aroma (Barut *et al*., 2022; Crişan *et al*., 2023), this species is widely preferred in Europe and Asia, particularly for cosmetic and pharmaceutical applications (Giannoulis *et al*., 2020; Crişan *et al*., 2023).

L. angustifolia is a perennial shrub species adapted to Mediterranean climatic conditions; while tolerant of climates characterized by hot summers and cool winters, it also exhibits ecological plasticity in stressful environments such as low fertility (Barut *et al*., 2022), eroded, or sloping soils (Pleguezuelo *et al*., 2009). Optimal soil growth conditions are well-drained and moderately fertile soils with a pH range of neutral to slightly alkaline (≈6.4-8.2) (Silva *et al*., 2017; Crişan *et al*., 2023). However, research aimed at improving the yield and essential oil content of *L. angustifolia* in soils that are nutrient deficient, poor in organic matter, or affected by erosion remains limited. Low nutrient soils and extended periods of severe drought negatively impact plant health, flower yield, and essential oil yield; nonetheless, organo-mineral fertilization and organic amendments (such as vermicompost and humic acid), along with phosphorus supplementation, have been documented to positively influence yield and essential oil composition (Chrysargyris *et al*., 2016; Silva *et al*., 2017; Peçanha *et al*., 2021; Sharafabad *et al*., 2022). Fertilization practices are critical agronomic elements influencing the growth, productivity, and essential oil quality of lavender. Organo-mineral fertilizers provide numerous benefits, including the enhancement of soil structure via organic matter, improved nutrient retention, and a more balanced release of mineral nutrients into the root zone (de Melo Benites *et al*., 2022; Ngo *et al*., 2022). For example, in a study conducted with *Lavandula dentata*, organo-mineral fertilizer applications were found to increase biomass and essential oil yield and, in certain doses, were even more effective than mineral fertilizers (Silva *et al*., 2017). Furthermore, studies comparing mineral and organic fertilization systems in *L. angustifolia* have reported that organic farming practices exert positive effects on some agronomic and essential oil parameters (Sharafabad *et al*., 2022).

The aim of this study is to determine how organo-mineral and mineral fertilizers affect the yield, essential oil content, and composition of the *L. angustifolia* 'Raya' variety grown in low fertility, calcareous soils and irrigated solely by rainwater.

Materials and Methods

The study was conducted in the Korkuteli district of Antalya province (30°12′ E longitude, 37°04′ N latitude). The district has an average altitude of approximately 1000 meters and features a transitional climate between Mediterranean and continental conditions. The research was carried out between 2020 and 2023 on the agricultural land of Akdeniz University Korkuteli Vocational School. The plant material used in this study was the 'Raya' cultivar of *Lavandula angustifolia* Mill. The experiment was set up according to a randomized complete block design consisting of a total of 16 plots, with four treatments and four replications. Each plot was arranged in a single row, with a row spacing of 1.30 m and an intra-row plant spacing of 30 cm. According to this planting arrangement, each plot contains 20 plants, resulting in a plot length of approximately 6.00 m, a plot width of 1.30 m, and a plot area of approximately 7.80 m^2. The experimental area, consisting of 16 plots, is approximately 200 m^2, taking edge effects into account. Yield measurements were performed by harvesting all plants in each plot, and the data obtained were evaluated according to plot averages. Plant seedlings were planted in the field in October 2020. Watering of the plants was limited to the initial watering given during

the planting of the seedlings; in subsequent years, only the water applied together with fertilizer applications was used. Apart from this, no additional watering was done, and the plants were grown only under natural rainfall conditions. The plants were unfertilized in the planting year, and harvest data from that year was not evaluated. Fertilizer applications were carried out from the second year onwards, with two applications made before flowering, in May 2022 and May 2023 (Figure 1).



Figure 1. Experimental field in Korkuteli district (Antalya, Türkiye) showing fertilizer application and harvest periods during the 2022 and 2023 growing seasons. In situ photographs taken by the authors during the field experiments (unpublished data).

Fertilizer applications were carried out using a solution prepared by dissolving the fertilizers in water. The prepared fertilizer solution was applied by hand to each plant, at a rate of 500 mL. The cut performed in July 2021 was not included in the evaluation. Therefore, the monthly average climatic data for the period after July 2021, corresponding to the 2022 and 2023 experimental years, are presented in Table 1. The climatic data were obtained from the nearest official meteorological station of the Turkish State Meteorological Service (TSMS) located in the Korkuteli district of Antalya Province. Harvests were performed at full flowering (July 2022 and 2023), focusing on flowering tops/inflorescences for essential oil production (Guitton *et al*., 2010).

Table 1. Monthly climatic data of Korkuteli during the 2022 and 2023 experimental years

Month	SD (h)	Ptot (mm)	Tmean (°C)	Tmax (°C)	Tmin (°C)	RHmean (%)
2022 Experimental Year						
Aug 2021	313.9	0.0	25.1	37.9	14.0	27.6
Sep 2021	251.0	1.6	19.4	31.0	5.8	40.6
Oct 2021	189.2	3.6	13.5	27.1	3.0	47.5
Nov 2021	139.2	14.4	9.9	24.7	−1.8	60.6
Dec 2021	87.1	167.4	4.0	14.9	−8.0	78.9
Jan 2022	105.7	58.4	0.8	13.2	−9.6	74.8
Feb 2022	134.3	68.8	3.6	19.2	−6.1	74.7
Mar 2022	187.0	22.4	2.2	16.7	−9.2	55.1
Apr 2022	221.4	3.4	12.4	25.9	−0.8	43.3
May 2022	270.5	39.0	15.5	29.7	4.2	50.6
Jun 2022	263.0	20.0	19.9	29.7	11.5	53.0
Jul 2022	326.3	0.0	23.9	36.2	13.3	29.8
Mean	207.38	33.25	12.52	25.52	1.36	53.04
2023 Experimental Year						
Aug 2022	305.5	13.8	22.9	34.4	11.3	52.0
Sep 2022	263.1	3.8	19.5	32.6	5.4	39.5
Oct 2022	191.4	11.2	14.2	31.3	1.3	52.1
Nov 2022	125.0	35.2	8.4	21.8	−1.4	68.2
Dec 2022	122.4	28.6	6.0	18.8	−3.0	83.8
Jan 2023	139.3	107.0	3.1	14.7	−4.3	77.1
Feb 2023	177.8	14.2	1.5	16.8	−8.8	60.4
Mar 2023	171.5	23.4	7.6	19.0	−3.7	67.5
Apr 2023	164.0	61.2	8.8	19.1	0.1	69.8
May 2023	183.7	134.0	13.4	27.0	2.1	77.2
Jun 2023	236.9	33.0	18.2	31.2	9.0	67.2
Jul 2023	319.1	0.0	24.6	36.7	13.1	30.1
Mean	199.98	38.78	12.35	25.28	1.76	62.08

SD (h): Total Sunshine Duration (h), Ptot (mm): Total Precipitation (mm), Tmean (°C): Mean Temperature (°C), Tmax (°C): Maximum Temperature (°C), Tmin (°C): Minimum Temperature (°C), RHmean (%): Mean Relative Humidity (%)

In the experiment, the treatments consisted of two organo-mineral fertilizers (OM-NP and OM-NK), one mineral fertilizer (M-N), and an unfertilized control. Total nitrogen (N) levels were held constant at 50 kg N ha^{-1} for all fertilization treatments, and fertilizer doses were adjusted accordingly. The experimental treatments and their nutrient compositions are presented in Table 2.

Table 2. Experimental treatments and nutrient compositions

Treatments	Fertilizer type	Commercial name	Main composition
OM-NP	Organo-mineral fertilizer (N + P)	Flower Replica® 5.20.0+Zn	Organic matter 12%; total N 5% (NO_3-N 2.5%, NH_4-N 2.5%); total P_2O_5 20%; Zn 3%; free amino acids 2%
OM-NK	Organo-mineral fertilizer (N + K)	Fruit Filler® 6.0.20+4% CaO + (B, Cu, Fe, Mn, Zn)	Organic matter 12%; total N 6% (NO_3-N 5%, NH_4-N 1%); K_2O 20%; CaO 4%; B 0.02%; Cu 0.02%; Fe 0.2%; Mn 0.2%; Zn 0.2%
M-N	Mineral fertilizer (N)	Terra Nitrogena® 16.0.0	Total N 16% (NH_4-N 8%, NO_3-N 8%)
Control	Unfertilized	–	No fertilizer (0 kg ha^{-1})

Before the experiment, soil samples were collected from a depth of 0-30 cm and airdried under room conditions for analysis. Soil texture was determined using the Bouyoucos hydrometer method, and sand, silt, and clay fractions were calculated accordingly. The pH and EC of soil suspensions prepared at a 1:2.5 soil-to-water ratio were determined using a pH meter (Thomas, 1996) and a pH-EC meter. The $CaCO_3$ content was measured with a Scheibler calcimeter (Schlichting *et al*., 1995), while organic matter was determined by the modified Walkley–Black method (Nelson and Sommers, 1996). Exchangeable potassium, calcium, and magnesium were determined following 1 N ammonium acetate extraction using ICP-OES (Nelson and Sommers, 1996). Micronutrients (Fe, Mn, and Zn) were determined by ICP-OES after DTPA extraction (Lindsay and Norvell, 1978).

The experimental field has a sloping topography, which increases the risk of surface runoff and erosion during rainy periods. An evaluation of the soil characteristics indicates several physical and chemical constraints affecting nutrient availability and overall soil fertility. The soil is characterized by a high lime content (26.6% $CaCO_3$) (FAO, 2006), a slightly alkaline reaction (pH 7.45) (USDA, 2017), and a clayey texture (21.3% sand, 16.0% silt, and 62.7% clay) (FAO, 2006), all of which are known to restrict nutrient dynamics in soils. The low organic matter content (2.0%) and insufficient total nitrogen level (0.1%) further limit soil fertility and nutrient supply (Havlin *et al*., 2017). The levels of available phosphorus (8.34 mg kg^{-1}) (Olsen *et al*., 1954), exchangeable magnesium (162 mg kg^{-1}) (USDA, 2017), zinc (0.56 mg kg^{-1}), and manganese (9 mg kg^{-1}) (Lindsay and Norvell, 1978) were all below their respective critical threshold levels, indicating the presence of multiple nutrient deficiencies. In contrast, the DTPA-extractable iron content (8.94 ppm) was within the medium sufficiency range (Lindsay and Norvell, 1978). Exchangeable K was 0.50 meq 100 g^{-1}, which corresponds to the medium category (0.4-0.6 meq 100 g^{-1}) based on standard soil test interpretation ranges (Marx *et al*., 2007); however, it has been reported that in calcareous and high-pH soils of Türkiye, particularly in the Mediterranean region, potassium availability is often restricted due to fixation by clay minerals (Eyüpoğlu, 1999). Exchangeable calcium content was very high (5503 ppm), a typical feature of calcareous soils, which may further intensify nutrient imbalances through antagonistic interactions with magnesium and micronutrients (Marschner, 2012). The electrical conductivity (EC) value of 0.14 mS cm^{-1} indicates that the soil is non-saline (FAO, 2006).

In the experiment, the fresh herb yield (t ha^{-1}) was determined from plants harvested with stems. The plants were then dried with their stems for 30 days in the shade at room temperature (approximately 25-30 °C). Following the drying process, the yield of dry herbs was assessed, and thereafter, the yield of dry flowers (t ha^{-1}) was quantified after separating the stems from the flowers in the dried samples. Essential oil yield (L ha^{-1}) was calculated by multiplying dry flower yield (t ha^{-1}) by the essential oil content on a dry matter basis.

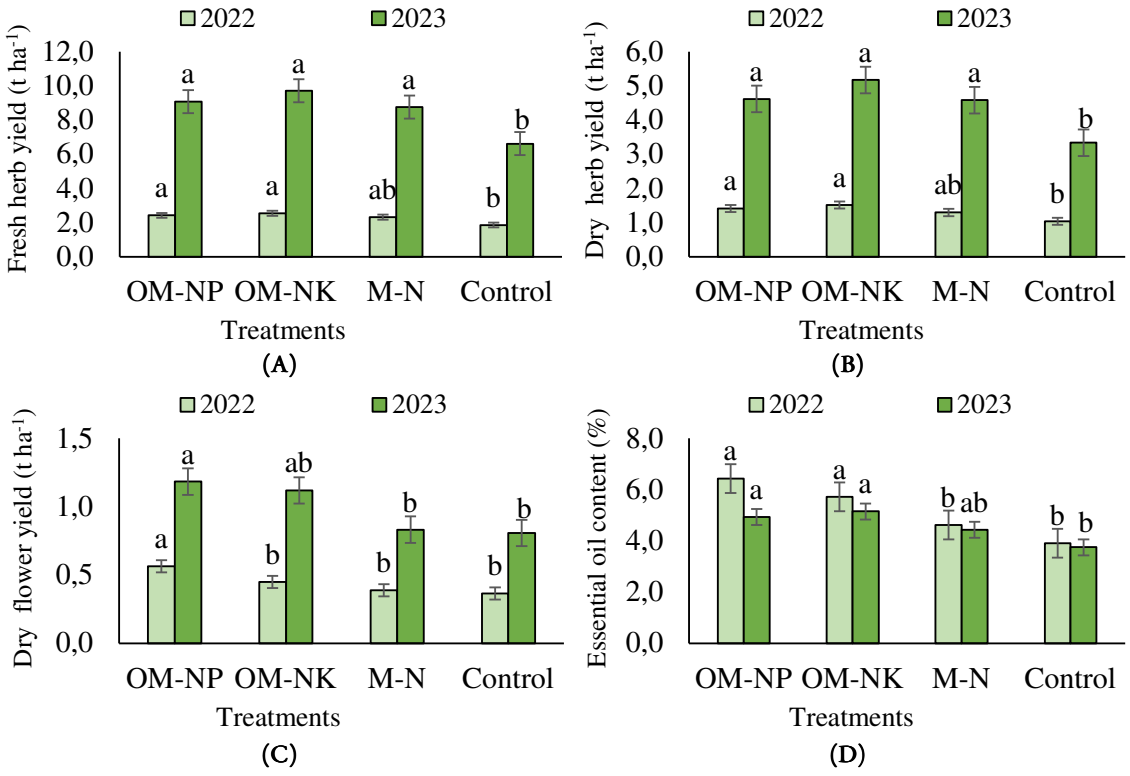
In the experiment, the essential oil content (%) was determined according to the standard procedure described in the European Pharmacopoeia 6.0 (2008), by subjecting 100 g of dried flower material to hydrodistillation with 1 L of water for 3 hours using a Clevenger apparatus (v w^{-1}). The composition of the essential oil samples was analysed by gas chromatography equipped with a flame ionization detector and a mass spectrometer (Agilent 5975C). For the analysis, an HP Innowax capillary column (60.0 m × 0.25 mm × 0.25 µm) was used. The essential oils were diluted with hexane at a ratio of 1:50, and GC-MS/FID analysis was carried out with a split ratio of 50:1. The injection volume was set at 1 µL with an injector temperature of 250 °C. Helium with 99.9% purity was used as the carrier gas at a constant flow rate of 1 mL/min. The oven temperature was initially set at 60 °C for 10 minutes, then increased at a rate of 20 °C/ min to 250 °C, where it was held for 8 minutes. The mass spectrometers were scanned in the range of 35-450 amu, with ionization performed in electron impact mode at 70 eV. The relative percentages of the constituents were calculated from GC-FID peak areas, and compound identification was based on comparison of mass spectra with the Wiley 7n, NIST 05, and Flavour and Fragrance Natural and Synthetic Compounds (ver. 1.3) libraries, as well as by comparison of experimentally determined retention indices (RI_{exp}) with literature retention indices (RI_{lit}) reported by Babushok *et al*. (2011). The essential oil extraction and constituent analyses were performed with three replicates per treatment. The results are presented as means ± standard error (SE).

The research data were analyzed according to the experimental design using the licensed SPSS statistical software package (SPSS Statistics Base, version 23.0). The experiment was conducted in a randomized complete block design with four replications. Data were subjected to analysis of variance (ANOVA), and mean comparisons were performed using Duncan's multiple range test. Differences among treatment means were considered statistically significant at $p < 0.05$.

Results and Discussion

Yield findings and essential oil content

Fertilizer applications resulted in higher fresh and dry herb yields of *L. angustifolia* in both experimental years when compared to the control application (Figure 2). The highest fresh and dry herb yields were obtained under the OM-NK treatment, which were 2.54 and 1.52 t ha^{-1} in 2022 and increased to 9.72 and 5.17 t ha^{-1} in 2023, respectively. These results are consistent with previous studies reporting that potassium-containing fertilizer applications can increase biomass production in lavender; Chrysargyris *et al*. (2016) reported that different potassium levels significantly increased fresh and dry biomass yield in *L. angustifolia*. Silva *et al*. (2017) reported that organo-mineral fertilization increased biomass and essential oil yield in *L. dentata*, while Peçanha *et al*. (2023) stated that different potassium sources (KCl and K_2SO_4) affected biomass production and essential oil composition in French lavender (*L. dentata*).



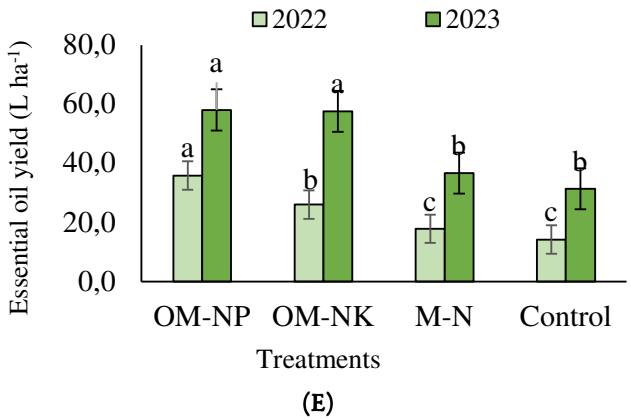


Figure 2. Effects of organo-mineral and mineral fertilizer applications and the control on (A) fresh herb yield (t ha^{-1}), (B) dry herb yield (t ha^{-1}), (C) dry flower yield (t ha^{-1}), (D) essential oil content (%), and (E) essential oil yield (L ha^{-1}) of *L. angustifolia* during the 2022 and 2023 growing seasons.

Four replicates were used, and the data represent the mean ± SE (n = 4). Different letters indicate significant differences among treatments according to Duncan's multiple range test at $p < 0.05$. OM-NP: Organo-mineral fertilizer containing N and P; OM-NK: Organo-mineral fertilizer containing N and K; M-N: Mineral nitrogen fertilizer; Control: No fertilizer

Fertilizer applications increased the dry flower and essential oil yield of *L. angustifolia* plants compared to control applications. The highest dry flower and essential oil yields were obtained under the OM-NP treatment, reaching 0.56 t ha^{-1} and 35.88 L ha^{-1} in 2022 and increasing to 1.18 t ha^{-1} and 58.07 L ha^{-1} in 2023, respectively (Figure 2). The results show that phosphorus-based organo-mineral fertilization increases both flower production and essential oil yield in lavender. Peçanha *et al*. (2021) evaluated five different phosphorus levels (0, 30, 60, 90 and 120 mg dm^{-3}) and reported that the number of flower heads, dry mass of flower heads, dry mass of the plant and essential oil yield increased up to 60 mg dm^{-3} in lavender, while higher phosphorus levels caused a decrease.

In 2022, the OM-NP application yielded the highest essential oil content of plants, at 6.43%, followed by OM-NK at 5.72%. In 2023, the highest essential oil content in plants was determined with the OM-NK treatment (5.15%), while the OM-NP treatment ranked second with 4.93%. In both years, the effects of phosphorus and potassium based organo-mineral fertilizer applications on the essential oil content of plants were statistically classified in the same letter group (Figure 2). Several studies examining the effects of increasing phosphorus doses on the essential oil content of *Lavandula* species have reported that dose is critical in phosphorus fertilization and that high phosphorus doses can lead to a reduction in essential oil content (Peçanha *et al*., 2021; Pryvedeniuk *et al*., 2023). Although our study did not include dose experiments, the results obtained are consistent with previous studies reporting the positive effects of potassium and phosphorus applications on the essential oil content of plants (Peçanha *et al*., 2023; Altay and Çalışkan, 2025;).

When the yields of *L. angustifolia* were evaluated across treatments in both experimental years, the minimum and maximum values recorded in 2022 ranged from 1.75 to 2.96 t ha^{-1} for fresh plant yield, from 0.63 to 1.76 t ha^{-1} for dry plant yield, from 0.27 to 0.63 t ha^{-1} for dry flower yield, and from 9.94 to 39.34 L ha^{-1} for essential oil yield. In 2023, the corresponding minimum and maximum values across treatments ranged from 4.67 to 10.62 t ha^{-1} for fresh plant yield, from 2.05 to 5.51 t ha^{-1} for dry plant yield, from 0.43 to 1.40 t ha^{-1} for dry flower yield, and from 14.14 to 67.57 L ha^{-1} for essential oil yield. When compared with previously published studies, the fresh herb, dry herb, and dry flower yields of *L. angustifolia* in the present study were lower in the first experimental year, whereas comparable or higher values were observed in the second year (Akçay *et al*., 2023; Pryvedeniuk *et al*., 2023). These results show that, despite the slope, low organic matter content, and high lime levels limiting soil fertility, plant yield increased significantly in the second year of the

experiment. The main reason for this increase is that plants develop more strongly after previous harvests, utilize resources efficiently even in low-fertility soils, and consequently produce a greater number of lateral shoots. Crişan *et al*. (2023) reported that the production capacity of narrow-leaved lavender increases from the second year onward, with yield increments exceeding 100%.

The minimum and maximum essential oil contents of the plants ranged from 3.71% to 7.18% in 2022, while this range was reduced to 3.26-5.97% in 2023. Although general climatic conditions during the growing season were largely similar in both years, the decrease in essential oil content observed in plants in 2023 compared with 2022 may be associated with climatic factors during the April-May-June period, when shoot development, bud formation, and the onset of flowering occur, such as shorter day length, higher relative humidity, and increased precipitation (Table 1), as well as plant-related factors including the yield-dilution effect associated with increased biomass production of plants and reduced stress levels resulting from the gradual adaptation of plants to the growing medium.

Essential oil composition

The effects of the applications on the essential oil constituents of *L. angustifolia* in 2022 and 2023 are given in Table 3. Essential oils obtained from the flowers of *L. angustifolia* are mainly composed of two major constituents, linalool and linalyl acetate. In the essential oils obtained from *L. angustifolia* flowers harvested in 2022, a total of 28 constituents were identified. Linalool was the major constituent, with mean values ranging from 47.35% to 51.26%, while the mean content of linalyl acetate ranged between 14.17% and 15.04%; these differences were not statistically significant. Linalool contents in essential oils from *L. angustifolia* were reported from 13.24% to 47%, and linalyl acetate levels can be anywhere from 8.0% to 40.9% (Kara and Baydar, 2012; Peçanha *et al*., 2021; Barut *et al*., 2022); the linalool and linalyl acetate contents identified in the current study align with the ranges established in these investigations. The highest levels of limonene (0.73%), 1,8-cineole (3.57%), 3-octanone (3.77%), and *cis*-linalool oxide (3.01%) in the essential oils of the plants were observed in the control treatment and were significantly higher than those recorded in the fertilized treatments. Significantly higher hexyl butanoate content (1.87%) was found to be present under the M-N treatment, whereas significantly higher *trans*-β-farnesene content (2.39%) was detected to be present under the OM-NP treatment compared with the other treatments.

Table 3. Chemical composition (%) of essential oils of *L. angustifolia* flowers under different treatments in 2022 and 2023

Compound	RI_{lit}	RI_{exp}	EO compounds (%) ± SE							
			2022				2023			
			OM-NP	OM-NK	M-N	Control	OM-NP	OM-NK	M-N	Control
Myrcene	1161	1174	0.63 ± 0.09	0.69 ± 0.03	0.65 ± 0.03	0.82 ± 0.04	0.53 ± 0.02	0.55 ± 0.03	0.49 ± 0.02	0.55 ± 0.07
Limonene	1198	1203	0.32 ± 0.06 b	0.35 ± 0.03 b	0.28 ± 0.03 b	0.73 ± 0.10 a	0.37 ± 0.02 AB	0.34 ± 0.02 B	0.34 ± 0.02 B	0.44 ± 0.04 A
1,8-Cineole	1211	1213	1.15 ± 0.26 b	1.23 ± 0.31 b	1.25 ± 0.12 b	3.57 ± 0.69 a	2.27 ± 0.08 AB	1.22 ± 0.10 C	1.90 ± 0.16 BC	3.20 ± 0.58 A
cis-β-Ocimene	1235	1246	0.44 ± 0.09	0.61 ± 0.02	0.39 ± 0.05	0.50 ± 0.01	0.35 ± 0.03	0.32 ± 0.04	0.27 ± 0.01	0.26 ± 0.04
trans-β-Ocimene	1250	1262	0.87 ± 0.25	0.99 ± 0.10	0.70 ± 0.08	0.76 ± 0.10	0.34 ± 0.02	0.42 ± 0.03	0.30 ± 0.03	0.37 ± 0.08
3-Octanone	1255	1269	2.44 ± 0.20 b	2.17 ± 0.12 b	3.20 ± 0.45 b	3.77 ± 0.47 a	2.30 ± 0.24	1.94 ± 0.37	1.68 ± 0.14	1.96 ± 0.12
Hexyl acetate	1274	1283	1.17 ± 0.11	1.10 ± 0.14	1.47 ± 0.10	1.33 ± 0.21	0.97 ± 0.15	0.95 ± 0.05	0.75 ± 0.07	0.98 ± 0.13

3-Octyl acetate	-	1345	0.40 ± 0.14	0.40 ± 0.06	0.67 ± 0.14	0.42 ± 0.13	-	-	-	-
1-Octen-3-yl acetate	1380	1386	0.44 ± 0.06	0.54 ± 0.05	0.66 ± 0.11	0.68 ± 0.15	0.76 ± 0.06	0.63 ± 0.07	0.51 ± 0.08	0.65 ± 0.10
3-Octanol	1392	1393	0.67 ± 0.15	0.62 ± 0.05	0.83 ± 0.08	1.00 ± 0.34	0.59 ± 0.09	0.45 ± 0.07	0.44 ± 0.02	0.47 ± 0.05
Hexyl butanoate	1414	1429	1.34 ± 0.08 bc	1.28 ± 0.05 c	1.87 ± 0.18 a	1.66 ± 0.06 ab	0.64 ± 0.04	0.62 ± 0.06	0.59 ± 0.10	0.61 ± 0.04
cis-Linalool oxide	1446	1478	1.30 ± 0.34 b	2.11 ± 0.46 ab	2.70 ± 0.40 a	3.01 ± 0.42 a	1.46 ± 0.29	1.67 ± 0.10	1.09 ± 0.25	1.39 ± 0.31
trans-Linalool oxide	1454	1497	1.06 ± 0.29	1.76 ± 0.37	2.10 ± 0.30	2.46 ± 0.37	1.01 ± 0.21	1.21 ± 0.09	0.70 ± 0.20	0.91 ± 0.22
Camphor	1515	1532	-	-	-	-	0.42 ± 0.02 B	0.33 ± 0.01 B	0.37 ± 0.03 B	0.63 ± 0.10 A
Linalool	1543	1533	51.26 ± 2.47	50.09 ± 2.34	47.35 ± 3.66	47.68 ± 4.33	53.09 ± 2.49	55.35 ± 1.75	57.49 ± 2.17	52.34 ± 2.72
Linalyl acetate	1554	1565	15.04 ± 3.03	14.24 ± 1.28	14.17 ± 1.60	11.57 ± 1.59	12.06 ± 1.64	11.84 ± 1.15	10.23 ± 0.67	10.53 ± 1.20
Lavandulyl acetate	1602	1583	3.49 ± 0.33	3.50 ± 0.33	3.48 ± 0.44	3.04 ± 0.28	4.60 ± 0.44	4.18 ± 0.18	4.44 ± 0.12	4.89 ± 0.41
Terpinen-4-ol	1601	1610	1.35 ± 0.67	2.93 ± 0.86	1.71 ± 0.57	1.06 ± 0.49	3.43 ± 0.43	1.97 ± 0.41	3.12 ± 0.39	2.77 ± 0.88
β-Caryophyllene	1599	1612	1.14 ± 0.29	1.24 ± 0.14	0.50 ± 0.07	0.83 ± 0.22	-	-	-	-
trans-*β*-Farnesene	1664	1695	2.39 ± 0.30 a	2.06 ± 0.17 ab	1.33 ± 0.23 b	1.62 ± 0.21 b	0.73 ± 0.13 B	0.76 ± 0.06 B	1.18 ± 0.06 A	0.86 ± 0.13 AB
Lavandulol	1679	1686	1.31 ± 0.19	1.29 ± 0.10	1.22 ± 0.26	1.21 ± 0.16	1.43 ± 0.13	1.75 ± 0.05	2.19 ± 0.22	1.96 ± 0.25
Cryptone	1675	1690	-	-	-	-	0.52 ± 0.04 B	0.36 ± 0.03 B	0.42 ± 0.03 B	0.71 ± 0.09 A
α-Terpineol	1694	1706	3.23 ± 0.28	3.18 ± 0.16	3.34 ± 0.41	2.90 ± 0.29	3.39 ± 0.33	3.73 ± 0.22	3.02 ± 0.09	3.10 ± 0.09
Borneol	1700	1719	1.63 ± 1.12	1.33 ± 0.41	1.52 ± 0.50	3.44 ± 1.03	1.72 ± 0.32 B	1.12 ± 0.10 B	1.42 ± 0.28 B	2.71 ± 0.22 A
Neryl acetate	1718	1733	0.94 ± 0.10	0.85 ± 0.06	1.00 ± 0.10	0.88 ± 0.06	0.79 ± 0.08	0.86 ± 0.06	0.71 ± 0.05	0.76 ± 0.03
Geranyl acetate	1751	1765	1.57 ± 0.15	1.34 ± 0.10	1.63 ± 0.26	1.22 ± 0.11	1.55 ± 0.17	1.67 ± 0.13	1.34 ± 0.09	1.40 ± 0.05
Nerol	1795	1808	0.66 ± 0.05	0.61 ± 0.03	0.64 ± 0.09	0.53 ± 0.03	0.83 ± 0.14	0.95 ± 0.05	0.85 ± 0.04	1.04 ± 0.08
Geraniol	1839	1857	1.76 ± 0.19	1.56 ± 0.12	1.70 ± 0.22	1.38 ± 0.14	1.62 ± 0.27	2.01 ± 0.17	1.66 ± 0.09	1.74 ± 0.06
Caryophyllene oxide	1986	2008	1.60 ± 0.41	1.77 ± 0.17	3.12 ± 1.11	1.78 ± 0.22	1.87 ± 0.27	2.49 ± 0.31	2.11 ± 0.43	2.31 ± 0.55
t-Cadinol	2170	2187	0.45 ± 0.08	0.23 ± 0.01	0.58 ± 0.32	0.32 ± 0.07	0.43 ± 0.07	0.37 ± 0.01	0.44 ± 0.06	0.50 ± 0.19

RI_{lit}**:** Retention indices reported in the literature (Babushok *et al*., 2011); RI_{exp}: Retention indices as determined on a HP Innowax column using a homologous series of n-alkanes; Values are mean ± standard error (SE). Different letters within the same row indicate significant differences at $p \leq 0.05$. Different lowercase letters within the same row indicate significant differences among treatments in 2022, whereas different uppercase letters indicate significant differences in 2023

In 2023, twenty-eight different constituents were identified in essential oils obtained from the flowers of *L. angustifolia*. In the essential oils of *L. angustifolia*, linalool, the predominant constituent, showed mean values ranging from 52.34% to 57.49%, whereas linalyl acetate, the second major constituent, showed mean values ranging from 10.23% to 12.06%; the treatments did not have a statistically significant effect on the contents of these constituents. The highest levels of limonene (0.44%), 1,8-cineole (3.20%), camphor (0.63%), cryptone (0.71%), and borneol (2.71%) in the essential oils of the plants were observed in the control treatment and were significantly higher than those recorded in the fertilized treatments. The highest *trans*-*β*-farnesene content (1.18%) in the essential oils of the plants was recorded under the M-N treatment. Previous studies have reported the variable responses of essential oil constituents to fertilizer applications. Mavandi *et al*. (2021) reported that organic fertilizers (cow manure and vermicompost) increased the proportions of limonene and 1,8-cineole in lavender essential oils compared with the control treatments. Chrysargyris *et al*. (2016) indicated that different potassium fertilization levels affected the content of 1,8-cineole, one of the major constituents of essential oils in the leaves of *L. angustifolia*; however, this compound did not exhibit a consistent increasing trend but rather showed a fluctuating pattern with increasing potassium levels.

Conclusions

This study demonstrated that organo-mineral fertilizers significantly increased yield in *L. angustifolia* grown under rainfed conditions in soils with fertility-limiting characteristics, including high lime content, low organic matter, and sloping terrain, during both experimental years. Among the applications, potassium-based organo-mineral fertilization (OM-NK) resulted in the highest fresh and dry plant yields and was effective in enhancing plant growth and biomass production. In contrast, phosphorus-based organo-mineral fertilization (OM-NP) was more effective in increasing dry flower and essential oil yields, highlighting the importance of phosphorus nutrition for generative development and oil production in lavender. Although fertilizer applications significantly affected yield parameters, their effects on essential oil composition were limited. In both experimental years, linalool and linalyl acetate were the dominant constituents of the essential oil, and their relative proportions were not significantly influenced by the treatments. Organo-mineral fertilization has increased yield while largely preserving the essential oil composition in *L. angustifolia* grown in rain-fed and low-fertility soil conditions, and therefore can be considered a suitable alternative or supplementary fertilization option for farmers under such growing conditions.

Authors' Contributions

Conceptualization: IKO; Data curation: IKO, FAV; Formal analysis: IKO; Funding acquisition: IKO, FAV; Investigation: IKO; Methodology: IKO; Project administration: IKO; Resources: IKO, FAV; Software: IKO; Supervision: IKO; Validation: IKO; Visualization: IKO; Roles/Writing - original draft: IKO; and Writing - review & editing: IKO, FAV.

Acknowledgements

This research did not obtain a specific grant from funding sources in the public, commercial, or nonprofit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Akçay S, Tunalı SP, Gürbüz T, Dağdelen N (2023). Determination of optimal deficit irrigation strategies for yield and yield components of lavender (*Lavandula angustifolia* Mill.) in semi-arid conditions. Applied Ecology and Environmental Research 21(6):6023-6039. *https://dx.doi.org/10.15666/aeer/2106_60236039*

Altay GD, Çalişkan S (2025). Effect of development of different doses of phosphorus and sulfur on essential oil amount and bioactive substances in *Lavandula angustifolia* (Mill.) plant. Journal of Animal and Plant Sciences 35(5):1457-1466. *https://doi.org/10.36899/JAPS.2025.5.0125*

Babushok VI, Linström PJ, Zenkevich IG (2011). Retention indices for frequently reported compounds of plant essential oils. Journal of Physical and Chemical Reference Data 40(4):1-47. *https://doi.org/10.1063/1.3653552*

Barut M, Tansı LS, Karaman S (2022). Essential oil composition of lavender (*Lavandula angustifolia* Mill.) at various plantation ages and growth stages in the Mediterranean region. Turkish Journal of Agriculture - Food Science and Technology 10(4):746-753. *https://doi.org/10.24925/turjaf.v10i4.746-753.5051*

Chrysargyris A, Panayiotou C, Tzortzakis N (2016). Nitrogen and phosphorus levels affected plant growth, essential oil composition and antioxidant status of lavender plant (*Lavandula angustifolia* Mill.). Industrial Crops and Products 83:577-586. *https://doi.org/10.1016/j.indcrop.2015.12.067*

Crişan I, Ona A, Vârban D, Muntean L, Vârban R, Stoie A, ... Morea A (2023). Current trends for lavender (*Lavandula angustifolia* Mill.) crops and products with emphasis on essential oil quality. Plants 12(2):357. *https://doi.org/10.3390/plants12020357*

de Melo Benites V, Dal Molin SJ, Menezes JFS, Guimarães GS, de Almeida Machado PLO (2022). Organomineral fertilizer is an agronomic efficient alternative for poultry litter phosphorus recycling in an acidic ferralsol. Frontiers in Agronomy 4:785753. *https://doi.org/10.3389/fagro.2022.785753*

European Pharmacopoeia Commission (2008). Lavender oil. In: European Pharmacopoeia. Council of Europe (6th ed), Strasbourg, France 1338e: 2244-2245.

Eyüpoğlu F (1999). Türkiye Topraklarının Verimlilik Durumu [Fertility Status of Soils in Türkiye]. T.C. Tarım ve Köyişleri Bakanlığı, Toprak ve Gübre Araştırma Enstitüsü Yayınları.

Fahimnia F, Nemattalab M, Hesari Z (2024). Development and characterization of a topical gel containing lavender (*Lavandula angustifolia*) oil loaded solid lipid nanoparticles. BMC Complementary Medicine and Therapies 24(1):44. *https://doi.org/10.1186/s12906-024-04440-2*

Food and Agriculture Organization of the United Nations (FAO) (2006). Guidelines for soil description (4th ed.). FAO, Rome, Italy. Retrieved 2026 February 16 from *https://www.fao.org/4/a0541e/a0541e.pdf*

Giannoulis KD, Evangelopoulos V, Gougoulias N, Wogiatzi E (2020). Could bio-stimulators affect flower, essential oil yield, and its composition in organic lavender (*Lavandula angustifolia*) cultivation? Industrial Crops and Products 154:112611. *https://doi.org/10.1016/j.indcrop.2020.112611*

Guitton Y, Nicolè F, Moja S, Valot N, Legrand S, Jullien F, Legendre L (2010). Differential accumulation of volatile terpene and terpene synthase mRNAs during lavender (*Lavandula angustifolia* and *L.* × *intermedia*) inflorescence development. Physiologia Plantarum 138(2):150-163. *https://doi.org/10.1111/j.1399-3054.2009.01315.x*

Havlin JL, Tisdale SL, Nelson WL, Beaton JD (2017). Soil fertility and fertilizers: An introduction to management (8th ed). Pearson India Education Services Pvt. Ltd. Uttar Pradesh, India.

Héral B, Stierlin É, Fernandez X, Michel T (2021). Phytochemicals from the genus *Lavandula*: A review. Phytochemistry Reviews 20(4):751-771. *https://doi.org/10.1007/s11101-020-09719-z*

Kara N, Baydar H (2012). Essential oil contents and composition of lavenders and lavandins cultivated in Turkey. Research on Crops 13(2):675-681.

Kayiran SD, Bolgen UMG, Cevikelli T, Kızılyıldırım S, Yıldır B, Ferahoglu E, ... S, Ozogul F (2025). Chemical composition and antibacterial properties of microemulsion and microemulgel formulations containing *Lavandula angustifolia* Mill. essential oils. Industrial Crops and Products 226:120654. *https://doi.org/10.1016/j.indcrop.2025.120654*

Lindsay WL, Norvell WA (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal 42(3):421-428. *https://doi.org/10.2136/sssaj1978.03615995004200030009x*

Marschner P (2012). Marschner's mineral nutrition of higher plants (3rd ed). In: Marschner P (Eds). Academic Press (3rd ed). *https://doi.org/10.1016/c2009-0-63043-9*

Marx ES, Hart J, Stevens R (2007). Soil test interpretation guide (EC 1478). Oregon State University Extension Service, Corvallis, USA. Retrieved 2026 February 16 from *https://www.haifa-group.com/sites/default/files/2024-03/ec1478.pdf*

Mavandi P, Abbaszadeh B, Emami Bistgani Z, Barker AV, Hashemi M (2021). Biomass, nutrient concentration and the essential oil composition of lavender (*Lavandula angustifolia* Mill.) grown with organic fertilizers. Journal of Plant Nutrition 44(20):3061-3071. *https://doi.org/10.1080/01904167.2021.1936037*

Nelson DW, Sommers LE (1996). Total carbon, organic carbon, and organic matter. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Johnston CT, Sumner ME (Eds). Methods of soil analysis: Part 3 - Chemical methods. Soil Science Society of America and American Society of Agronomy, Madison, WI, USA pp 961-1010. *https://doi.org/10.2136/sssabookser5.3.c34*

Ngo HTT, Watts-Williams SJ, Panagaris A, Baird R, McLaughlin MJ, Cavagnaro TR (2022). Development of an organo-mineral fertiliser formulation that improves tomato growth and sustains arbuscular mycorrhizal colonisation. Science of the Total Environment 815:151977. *https://doi.org/10.1016/j.scitotenv.2021.151977*

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. US Government Printing Office, Washington DC.

Peçanha DA, Freitas MSM, Vieira ME, Cunha JM, de Jesus AC (2021). Phosphorus fertilization affects growth, essential oil yield and quality of true lavender in Brazil. Industrial Crops and Products 170:113803. *https://doi.org/10.1016/j.indcrop.2021.113803*

Peçanha DA, Freitas MSM, Cunha JM, Vieira ME, de Jesus AC (2023). Mineral composition, biomass and essential oil yield of French lavender grown under two sources of increasing potassium fertilization. Journal of Plant Nutrition 46(3):344-355. *https://doi.org/10.1080/01904167.2022.2068430*

Pleguezuelo CRR, Zuazo VHD, Raya AM, Martínez JRF, Rodríguez BC (2009). High reduction of erosion and nutrient losses by decreasing harvest intensity of lavender grown on slopes. Agronomy for Sustainable Development 29(2):363-370. *https://doi.org/10.1051/agro:2008043*

Pryvedeniuk N, Hlushchenko L, Kutsyk T, Shatkovskyi A, Shatkovska K, Shevchenko T (2023). Influence of mineral fertilizers and planting density on the growth, development and yield of narrow-leaved lavender (*Lavandula angustifolia* Mill.). Agriculture and Forestry 69(2):165-180. *https://doi.org/10.17707/AgricultForest.69.2.13*

Schlichting E, Blume HP, Stahr K (1995). Bodenkundliches Praktikum [Practical soil science]. Blackwell Wissenschafts-Verlag, Berlin.

Sharafabad ZH, Abdipour M, Hosseinifarahi M, Kelidari A, Rashidi L (2022). Integrated humic acid and vermicomposting changes essential oil quantity and quality in field-grown *Lavandula angustifolia* L. intercropped with *Brassica nigra* L. Industrial Crops and Products 178:114635. *https://doi.org/10.1016/j.indcrop.2022.114635*

Silva SM, Luz JMQ, Nogueira PAM, Blank AF, Sampaio TS, Pinto JAO, Wisniewski A (2017). Organo-mineral fertilization effects on biomass and essential oil of lavender (*Lavandula dentata* L.). Industrial Crops and Products 103:133-140. *https://doi.org/10.1016/j.indcrop.2017.04.004*

Thomas GW (1996). Soil pH and soil acidity. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Johnston CT, Sumner ME (Eds). Methods of soil analysis: Part 3 – Chemical methods. Soil Science Society of America and American Society of Agronomy, Madison, WI, USA pp 475-490. *https://doi.org/10.2136/sssabookser5.3.c16*

United States Department of Agriculture (USDA) (2017). Soil Survey Manual (Agriculture Handbook No. 18). USDA–Natural Resources Conservation Service, Washington, DC, USA, p. 199. Retrieved 2026 February 16 from *https://www.nrcs.usda.gov/sites/default/files/2022-09/The-Soil-Survey-Manual.pdf*

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