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Application of combined fertilizers to improve growth, yield and essential oil composition of basil (*Ocimum basilicum* L.)

Tong Van Giang[1], Tran Thi Huyen[1], Nguyen Huu Hai[2]

[1] Hong Duc University, Thanh Hoa, Vietnam

[2] Plant Resources Center, Vietnam Academy of Agricultural Sciences, Ha Noi, Vietnam

Corresponding author: Tong Van Giang, tongvangiang@hdu.edu.vn

Basil (*Ocimum basilicum* L.) is a vital aromatic crop widely utilized in culinary and fragrance industries. The present study was conducted to implement a two-year field experiment (2019 and 2020) aimed to assess the impact of various fertilizers on the growth, yield, and essential oil composition of basil cultivated in Thanh Hoa Province, Vietnam. The fertilizer treatments included: no fertilizer (control), chemical fertilizer (NPK at 90-120-90 kg/ha), cow manure, chicken manure, and a combination of chemical fertilizer, cow manure, and chicken manure. The application of fertilizers resulted in significant improvements across various parameters compared to the control group. Basil plants treated with fertilizers exhibited increased height, lateral stem count, fresh and dry yields, chlorophyll and carotenoid content, essential oil yield, and essential oil content. The essential oil extracted from basil contained notable volatile compounds, with methyl chavicol, linalool, *β*-elemene, and *epi*-*α*-cadinol identified as the major constituents. The proportions of these compounds varied among the fertilizer treatments. Notably, the combined fertilization approach involving chemical fertilizers, cow manure, and chicken manure emerged as the most effective and significant in promoting basil growth and essential oil production. These findings not only contribute to the optimization of basil cultivation practices but also provide insights for the agricultural community, emphasizing the importance of balanced fertilization for maximizing the quality and yield of basil essential oil in the Vietnamese context.

Keywords: *Ocimum basilicum*, fertilizers, essential oil content, methyl chavicol, linalool

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ИЗУЧЕНИЕ И ИСПОЛЬЗОВАНИЕ ГЕНЕТИЧЕСКИХ РЕСУРСОВ РАСТЕНИЙ

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Применение комбинированных удобрений для улучшения роста, урожайности и эфирномасличного состава базилика (*Ocimum basilicum* L.)

Т. В. Гианг[1], Ч. Т. Хуен[1], Н. Х. Хай[2]

[1] Университет Хонг Дык, Тхань Хоа, Вьетнам

[2] Центр растительных ресурсов Вьетнамской академии сельскохозяйственных наук, Ханой, Вьетнам

Автор, ответственный за переписку: Тонг Ван Гианг, tongvangiang@hdu.edu.vn

Базилик (*Ocimum basilicum* L.) – жизненно важная ароматическая культура, широко используемая в кулинарии и парфюмерной промышленности. В настоящем исследовании двухлетний полевой эксперимент (2019 и 2020 г.) был направлен на оценку влияния различных удобрений на рост, урожайность и состав эфирного масла базилика, выращиваемого в провинции Тханьхоа, Вьетнам. Обработки удобрениями включали: отсутствие удобрений (контроль), химические удобрения (NPK в дозе 90-120-90 кг/га), коровий навоз, куриный помет и комбинацию химических удобрений, коровьего и куриного помета. Применение удобрений привело к значительным улучшениям по различным параметрам по сравнению с контрольной группой. Растения базилика, обработанные удобрениями, показали увеличение высоты, количества боковых стеблей, свежей и сухой урожайности, содержания хлорофилла и каротиноидов, выхода эфирного масла и содержания эфирного масла. Эфирное масло, экстрагированное из базилика, содержало летучие соединения, основными компонентами которых были метилхавикол, линалоол, β-элемен и эпи-α-кадинол. Пропорции этих соединений варьировались в зависимости от внесения удобрений. Примечательно, что комбинированный подход к внесению химических удобрений, коровьего и куриного помета оказался наиболее эффективным и значимым для стимулирования роста базилика и производства эфирного масла. Эти результаты не только способствуют оптимизации методов выращивания базилика, но и повышают информированность сельскохозяйственного сообщества, подчеркивая важность сбалансированного внесения удобрений для максимизации качества и урожайности эфирного масла базилика во вьетнамском контексте.

Ключевые слова: *Ocimum basilicum*, удобрения, содержание эфирного масла, метилхавикол, линалоол

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Introduction

Basil, scientifically known as *Ocimum basilicum* L., is a revered herb celebrated not only for its culinary contributions but also for the aromatic treasure it yields in the form of essential oil (Dhama et al., 2023). Originating from the tropical regions of Asia, particularly India, basil has spread its aromatic influence across the globe, becoming a staple in various cuisines and cultures (Shahrajabian et al., 2020). This herb is renowned for its distinctive, sweet aroma and robust flavor, which adds depth and character to a wide array of dishes. Its glossy green leaves, often used either fresh or dried, impart a unique and delightful taste to salads, pasta, soups, and many other culinary creations (Filip, 2017). Beyond its culinary applications, basil has a rich history in traditional medicine, where it is revered for its potential health benefits (Shahrajabian et al., 2020; Dhama et al., 2023). Basil essential oil is renowned for its therapeutic properties, including antimicrobial and anti-inflammatory characteristics (Kathirvel, 2016). In aromatherapy, it is often employed to alleviate stress, uplift the spirit, and promote mental clarity (Kathirvel, 2016).

The management of plant nutrition is undeniably one of the keystones in modern agricultural strategies (Roy et al., 2006). As the global population burgeons, the demand for agricultural products, including herbs and essential oils, continues to rise. Effective plant nutrition not only ensures optimal crop growth but also plays a crucial role in enhancing the nutritional content of the produce (Baligar et al., 2001; Newell-McGloughlin, 2008; Fageria, Moreira, 2011). By adopting precision nutrition strategies, farmers can tailor the nutrient requirements of plants, leading to increased yields, improved quality, and sustainable agricultural practices.

In the pursuit of sustainable and environmentally friendly agricultural practices, the utilization of organic fertilizers has gained prominence (Adugna, 2016). Organic fertilizers, such as compost and manure, contribute not only to enhanced soil fertility but also foster long-term sustainability (Verma et al., 2020). The adoption of organic fertilizers in Vietnam offers a dual benefit – it provides essential nutrients to plants while promoting soil health and reducing the environmental impact of conventional chemical fertilizers (Sharma, 2017; Singh et al., 2020). This shift towards organic fertilizers aligns with global efforts to create a more sustainable and ecologically responsible agricultural sector (Verma et al., 2020).

In Vietnam, where the cultivation of herbs and essential oils from basil has become a significant economic driver, addressing the challenge of increasing productivity without expanding cultivation areas has become imperative. This necessitates an innovative approach to agricultural practices, focusing on optimizing plant nutrition and employing organic fertilizers to enhance crop yields. In the present study, a field experiment was conducted to determine the effects of (1) chemical fertilizers (N, P, K), (2) organic manure (cow manure, and chicken manure), and (3) integrated fertilizers (N, P, K, cow manure, chicken manure) on the growth, yield and essential oil composition of basil.

Materials and methods

Characteristics of the experiment site

The study was conducted on basil cultivated in an open field during the years 2019 and 2020 at the experimental farm situated at Hong Duc University, Thanh Hoa Province (19°46'16"N and 105°46'47"E), Vietnam. The region experiences high rainfall, ranging from approximately 1600 to 2300 mm annually, with a mean annual temperature of 24°C. Soil samples were collected from a depth of 0 to 30 cm for physical and chemical analyses. The soil's physicochemical properties were determined as follows: electrical conductivity (EC) – 0.56 dS/m, potential of hydrogen (pH) – 7.14, organic carbon – 0.43%, organic matter – 9.13%, nitrogen (N) – 0.07%, phosphorus (P) – 0.01%, potassium (K) – 0.03%, and carbon/nitrogen (C/N) ratio – 6.14.

Plant materials and sowing seeds

Basil seeds (*Ocimum basilicum* L.) were purchased from the Vietnam High-tech Plant Seed Center. Subsequently, these seeds were planted in a greenhouse equipped with automated environmental controls, maintaining a day/night temperature of 25/20 °C, relative humidity of 65%, and utilizing natural light. During the initial two-week post-sowing period, the plants received daily watering, which transitioned to a weekly schedule after this period. Plastic germination trays served as the containers, and the growth medium employed was a peat-based substrate. Transplantation of the seedlings to the field site took place after 6 weeks.

Agronomic practices and experimental design

A field experiment was conducted using a randomized block design comprising five treatments and three replications. The treatments included T0 (control, without fertilizer), T1 (chemical fertilizers at the rate of 90 N – 120 P – 90 K kg/ha), T2 (15 t/ha of cow manure), T3 (9 t/ha of chicken manure), and T4 (a combination of chemical fertilizers with 30 N – 40 P – 30 K kg/ha, 5 t/ha of cow manure, and 3 t/ha of chicken manure). Urea ($CO(NH_2)_2$), triple superphosphate ($Ca(H_2PO_4)_2 \cdot H_2O$, and potassium sulfate (K_2SO_4) were used to apply N, P, and K, respectively. The chemical characteristics of cow manure and chicken manure can be found in Table 1. All fertilizers were incorporated into the soil one week before transplanting basil. Plots were irrigated immediately after transplanting and as needed throughout the growing seasons. No pesticides were employed during the experiment, and weed control was carried out manually. Harvesting was conducted on June 20 in the first year and June 28 in the second.

Measurement of some morpho-physiological traits

In both years, the harvesting of plants occurred at the full bloom stage, with the cut made 5 cm above the soil surface. The total fresh yield was documented and presented as t/ha. The number of lateral stems and plant height were determined, the latter measured with a ruler and expressed in cm. The total dry yield was measured and reported as t/ha after storing for 72 hours in an oven at 72°C. Concentrations of chlorophyll *a*/*b*, total chlorophyll, and carotenoids were assessed using a spectrophotometer following the method by T. T. Le et al. (2021).

Essential oil extraction

Plant material (200 g) for each treatment was dried and milled into a powder. Hydrodistillation was then carried out for 3 hours using a Clevenger-type apparatus, following the established procedures (Giang et al., 2023). The essential oils were dried with anhydrous sodium sulfate and stored in amber vials at 4°C. The process of hydrodistillation was repeated in triplicate, and the essential oil yield (%, v/w) was subsequently calculated.

Essential oil analysis

The chemical compositions of the basil essential oils were analyzed using gas chromatography–flame ionization detec-

Table 1. Chemical characteristics of cow manure and chicken manure used in the experiment

Таблица 1. Химические характеристики коровьего навоза и куриного помета, использованных в эксперименте

Parameter	Cow manure	Chicken manure
EC (dS/m)	1.68	6.73
pH	7.91	7.24
Organic carbon (%)	26.47	19.54
Organic matter (%)	30.11	32.67
Total N (%)	1.92	2.36
Available P (%)	0.84	0.80
Available K (%)	0.62	1.13
C/N	13.79	8.28

tion (GC–FID) and gas chromatography–mass spectrometry (GC–MS), following previously established procedures (Thin et al., 2023). The GC–FID analysis employed an Agilent Technologies 7890A GC equipped with FID and an HP-5MS capillary column (30 m × 0.25 mm, 0.25 µm film thickness). A ramp oven temperature was applied, beginning at 60 °C for 5 min, then increased to 220°C at a rate of 4°C/min, and held at 220°C for 10 min. The injector and detector temperatures were set at 250 and 260°C, respectively. Helium was used as the carrier gas at a flow rate of 1 mL/min, with a 1 : 10 split mode ratio in the injector. For each sample, the essential oil was diluted in n-hexane (at a ratio of 1 : 100) and injected (1 µL) into the GC system. The quantification of essential oil components was achieved through peak area normalization without correction factors.

The GC–MS analysis utilized an Agilent 7890A gas chromatograph coupled to an HP 5973 mass spectrometer with an HP-5MS capillary column (30 m × 0.25 mm, 0.25 µm film thickness). The analysis was performed in the EI mode, with an electron energy of 70 eV, a scan range of 35–350 amu, and a transfer line temperature of 280°C. Helium was the carrier gas with a flow rate of 1 mL/min, and the injector temperature was set to 250°C, following the same oven temperature program as in GC–FID. Identification of essential oil constituents was accomplished through computer matching with MS libraries (Adams, 2007; NIST, 2018), along with co-injection with authentic standards (linalool, methyl chavicol, and β-elemene) from Sigma-Aldrich, USA. Additionally, the calculation of temperature-programmed linear retention indices was conducted using a homologous series of n-alkanes (Sigma, USA), and the results were compared with those reported in the literature (Adams, 2007; NIST, 2018).

Statistical analysis

The results were presented as means and standard errors. To evaluate statistically significant differences between treatments, means were compared using the analysis of variance (ANOVA). The analyses were conducted on a personal computer utilizing SPSS™ software (SPSS Inc., Illinois, USA). Treatment means were further compared through the least significant difference test at a significance level of $p < 0.05$.

Results and discussion

Growth and morphophysiological characteristics

The application of various fertilizer treatments demonstrated a positive influence on basil growth. Notably, the highest plant height was observed in plants treated with the combination of fertilizers in the T4 treatment (Table 2). The use of combined fertilization, involving chemical fertilizers, cow manure, and chicken manure, resulted in a significant increase in plant height to 47.21 cm. Additionally, the number of lateral stems was increased in all amended plots as compared to the control (see Table 2). Among them, the number of lateral stems did not significantly change among the treatments of combined fertilizer and chemical fertilizer and reached the highest values, 16.88 and 16.74 per plant, respectively. These findings align with the earlier study by V. Pandey et al. (2016), who reported improved growth attributes in basil when using combined fertilizers in India. The enhancement of soil physicochemical properties through combined fertilizers played a crucial role in promoting crop growth and development. An increased supply of nutrients likely contributed to a rise in plant height and lateral stem count, intensified physiological activities, and enhanced photo-assimilate production, thereby boosting the overall growth (Fattahi et al., 2019; Teliban et al., 2020).

Furthermore, all fertilizers resulted in increased fresh and dry yields of basil in comparison to the control group, as shown in Table 2. The highest fresh and dry yields were recorded for the T4 treatment when the combined fertilizer was utilized. Specifically, the fresh and dry yields of basil reached 13.57 and 3.69 t/ha, respectively. Superior yields attributed to the use of various fertilizers may be explained by the synergy of organic and chemical fertilizers, inducing higher biomass production and improved plant growth. G. S. Teliban et al. (2020) also noted a significant influence of fertilizing systems on basil growth, dry matter, and herb production.

As shown in Table 2, the application of different fertilizers significantly increased the concentrations of photosynthetic pigments in basil leaves. The T4 treatment, utilizing the combined fertilizer, exhibited the highest chlorophyll *a*/*b*, total chlorophyll, and carotenoid contents. This increase in chlorophyll levels could be directly linked to the balanced nutrient

Table 2. **The effect of fertilizers on the growth and physiological characteristics of basil**

Таблица 2. **Влияние удобрений на рост и физиологические характеристики базилика**

Treatments	Plant height (cm)	Lateral stems (pcs. per plant)	Fresh yield (t/ha)	Dry yield (t/ha)	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total chlorophyll (mg/g)	Carotenoid (mg/g)
T0	40.12 ± 0.71 c	12.07 ± 0.81 c	7.40 ± 0.42 c	1.72 ± 0.12 c	0.66 ± 0.03 c	0.18 ± 0.01 c	0.84 ± 0.03 d	0.36 ± 0.08 c
T1	46.08 ± 0.97 ab	16.74 ± 0.90 a	12.53 ± 0.67 ab	3.31 ± 0.28 ab	0.95 ± 0.03 b	0.42 ± 0.02 a	1.37 ± 0.06 b	0.44 ± 0.11 a
T2	44.78 ± 0.82 b	15.94 ± 0.87 ab	10.14 ± 0.54 b	2.88 ± 0.25 b	0.93 ± 0.04 b	0.26 ± 0.02 b	1.19 ± 0.04 c	0.41 ± 0.09 b
T3	43.91 ± 0.84 b	14.52 ± 0.85 b	9.46 ± 0.53 b	2.74 ± 0.10 b	0.92 ± 0.05 b	0.25 ± 0.02 b	1.17 ± 0.06 c	0.41 ± 0.09 b
T4	47.21 ± 1.09 a	16.88 ± 0.94 a	13.57 ± 0.72 a	3.69 ± 0.20 a	1.08 ± 0.04 a	0.44 ± 0.03 a	1.52 ± 0.05 a	0.44 ± 0.12 a

Note: **T0** – control, T1 – chemical fertilizers, T2 – cow manure, T3 – chicken manure, and T4 – chemical fertilizers + cow manure + chicken manure. Results are means of three measurements ± standard errors. Within each column, values associated with different letters are significantly different according to Tukey's test at $p < 0.05$

Примечание: T0 – контроль, T1 – химические удобрения, T2 – коровий навоз, T3 – куриный помет, T4 – химические удобрения + коровий навоз + куриный помет. Результаты представлены как средние трех измерений ± стандартные ошибки среднего. В каждом столбце значения, сопровождающиеся различными буквами, достоверно различаются по критерию Тьюки при $p < 0,05$

supply in the soil resulting from the combined use of organic and chemical fertilizers. The intense green color, a preferred quality criterion for consumers, was achieved through integrated fertilizer application, with nitrogen playing a crucial role as the building block for amino acids, protein synthesis, and chlorophyll (Wen et al., 2019). According to V. Pandey et al. (2016), the provision of nitrogen during the leaf growth phase stimulates chloroplast formation, consequently enhancing the chlorophyll content in the leaves. Substantial nitrogen content in the growing tissue also acts as a catalyst for enzymes responsible for chlorophyll synthesis (Leghari et al., 2016; Wen et al., 2019).

Essential oil yield

Our findings highlight a substantial impact of fertilizer treatments on the basil essential oil yield. All treated plots demonstrated oil yields higher than the control (Figure 1). Specifically, the application of the combined fertilizer (T4) resulted in the highest essential oil yield at 1.28 ± 0.04%, followed by chemical fertilizer (T1) at 1.09 ± 0.05%. In contrast, the utilization of cow manure (T2) and chicken manure (T3) showed no significant difference in essential oil yields, with values of 0.92 ± 0.03% and 0.90 ± 0.04%, respectively. The essential oil yield of the control (T0) was the lowest, measuring only 0.71 ± 0.06%. The increased essential oil yield observed in basil under combined fertilizer treatments is likely attributed to the enhanced availability of essential elements, such as nitrogen, and/or an increase in the cation exchange capacity (CEC) of the soil (Siddique, 2015). This enhancement may facilitate the accumulation of nutrients in the plant, leading to higher biomass and production of secondary metabolites (Anwar et al., 2005; Pandey et al., 2016). Nitrogen, in particular, plays a crucial role in the development and division of cells containing essential oil, as well as in essential oil channels, secretory ducts, and glandular trichomes (Said-Al Ahl et al., 2009; Leghari et al., 2016). The findings of V. Pandey et al. (2016) support the idea that nutrient availability, resulting from fertilizer application, significantly increases oil yield in basil. Therefore, a combination of different fertilizers can be considered a comprehensive source of nutrients in sustainable agricultural systems (Alizadeh et al., 2010; Pandey, Patra, 2015; Keshavarz et al., 2018; Da Cunha Honorato et al., 2022).

Chemical composition of the essential oil

The results of the GC and GC–MS analyses of the essential oil extracted from the aerial parts of basil are outlined in Table 3. The main components influencing the quality of basil essential oil were identified as follows: methyl chavicol (39.27–28.78%), linalool (31.04–27.25%), *β*-elemene (7.92–4.34%), and *epi*-*α*-cadinol (6.30–4.09%). This composition aligns with the findings reported by other researchers examining the chemical compounds of basil essential oil (Omidbaigi et al., 2003; Sajjadi, 2006; Stanojevic et al., 2017).

The analysis of essential oils derived from the aerial parts of basil revealed that the fertilizer treatments had a noticeable impact on the percentage of these compounds, as illustrated in Figure 2. In fact, the application of fertilizers resulted in an enhancement of essential oil quality, as indicated by the increased percentages of the marker compounds compared to the control conditions. Notably, the combined fertilization approach in this study exhibited the most significant increase in the content of the main compounds found in basil essential oil. Previous studies corroborated that various fertilizers, including both chemical and organic manure, can exert an effect on the composition of essential oils (Bistgani et al., 2018; Hamedi et al., 2022; Yang et al., 2022).

The variability in the chemical composition of essential oils is closely linked with the overall physiology of the plant (Li et al., 2020). It appears that the positive effect of combined

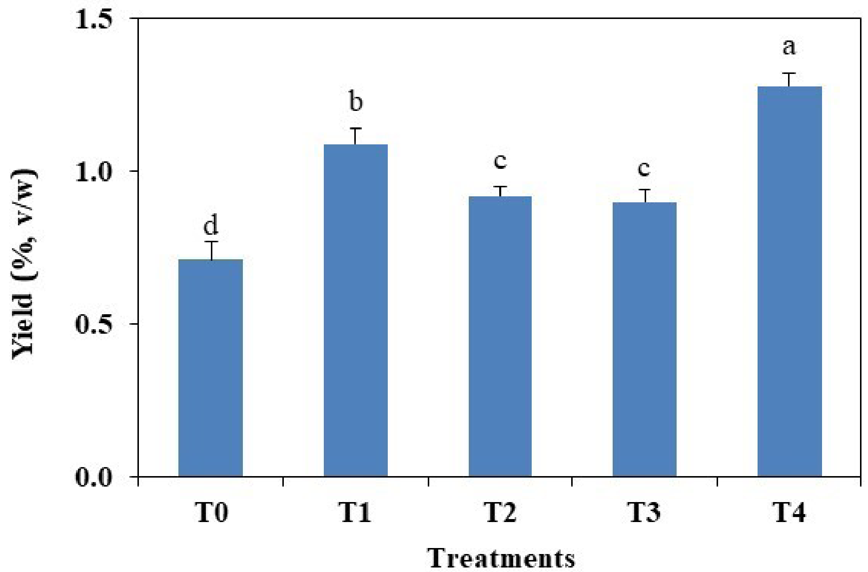

Fig. 1. The effect of fertilizers on the essential oil yield (%, v/w) of basil. T0 – control, **T1** – chemical fertilizers, **T2** – cow manure, **T3** – chicken manure, and **T4** – chemical fertilizers + cow manure + chicken manure. Results are means of three measurements ± standard errors. Values associated with different letters are significantly different according to Tukey's test at $p < 0.05$

Рис. 1. Влияние удобрений на выход эфирного масла (%, v/w) базилика. T0 – контроль, **T1** – химические удобрения, **T2** – коровий навоз, **T3** – куриный помет, **T4** – химические удобрения + коровий навоз + куриный помет. Результаты представлены как средние трех измерений ± стандартные ошибки среднего. Значения, сопровождающиеся различными буквами, достоверно различаются по критерию Тьюки при p < 0,05

Table 3. The effect of fertilizers on the essential oil composition of basil (%)
Таблица 3. Влияние удобрений на состав эфирного масла базилика (%)

Compound [a]	RI [b]	RI [c]	Treatments				
			T0	T1	T2	T3	T4
α-Pinene	939	932	1.15 ± 0.05	0.18 ± 0.02	0.11 ± 0.01	0.32 ± 0.02	0.21 ± 0.02
Camphene	955	946	0.20 ± 0.02	0.10 ± 0.01	0.27 ± 0.03	0.21 ± 0.01	0.11 ± 0.01
Sabinene	978	969	0.17 ± 0.01	– [d]	–	0.28 ± 0.02	0.15 ± 0.01
β-Pinene	984	974	2.25 ± 0.04	0.33 ± 0.01	0.41 ± 0.03	1.61 ± 0.04	0.42 ± 0.02
Myrcene	991	988	0.23 ± 0.02	0.48 ± 0.02	0.32 ± 0.03	0.10 ± 0.01	0.28 ± 0.03
Limonene	1034	1024	0.31 ± 0.02	0.34 ± 0.02	0.10 ± 0.01	0.27 ± 0.01	0.13 ± 0.01
1,8-Cineole	1037	1026	2.40 ± 0.12	1.74 ± 0.04	1.62 ± 0.05	2.98 ± 0.06	1.17 ± 0.04
(*Z*)-*β*-Ocimene	1039	1032	1.87 ± 0.07	1.68 ± 0.03	2.89 ± 0.05	2.33 ± 0.05	0.27 ± 0.01
(*E*)-*β*-Ocimene	1048	1044	2.64 ± 0.08	0.75 ± 0.02	1.24 ± 0.06	0.89 ± 0.03	0.94 ± 0.02
Terpinolene	1087	1086	–	0.37 ± 0.01	0.53 ± 0.02	–	0.18 ± 0.01
Linalool	1101	1095	27.25 ± 0.17	30.89 ± 0.28	28.05 ± 0.19	27.76 ± 0.20	31.04 ± 0.41
Camphor	1145	1141	0.38 ± 0.02	0.46 ± 0.01	0.28 ± 0.03	0.22 ± 0.01	0.35 ± 0.02
Menthone	1154	1148	0.49 ± 0.03	0.15 ± 0.01	0.32 ± 0.02	0.29 ± 0.02	0.27 ± 0.01
iso-Menthone	1164	1158	0.15 ± 0.01	0.26 ± 0.01	0.27 ± 0.01	0.10 ± 0.01	0.19 ± 0.01
Menthol	1172	1167	0.36 ± 0.02	0.82 ± 0.02	0.54 ± 0.02	0.67 ± 0.03	0.46 ± 0.02
Terpinen-4-ol	1185	1174	–	0.13 ± 0.01	0.19 ± 0.01	0.24 ± 0.02	–
α-Terpineol	1197	1186	1.47 ± 0.02	0.11 ± 0.01	0.36 ± 0.02	0.39 ± 0.02	0.21 ± 0.01
Methyl chavicol	1200	1195	28.78 ± 0.21	36.05 ± 0.62	34.24 ± 0.28	31.18 ± 0.42	39.27 ± 0.58
Geraniol	1252	1249	0.20 ± 0.01	0.28 ± 0.01	0.49 ± 0.02	1.41 ± 0.06	0.39 ± 0.02
Bornyl acetate	1286	1284	0.18 ± 0.01	0.78 ± 0.02	0.12 ± 0.01	0.35 ± 0.02	0.25 ± 0.02
δ-Elemene	1339	1335	0.46 ± 0.02	0.96 ± 0.03	0.30 ± 0.01	0.20 ± 0.01	0.36 ± 0.01
α-Cubebene	1352	1345	0.39 ± 0.01	0.27 ± 0.01	0.21 ± 0.01	0.11 ± 0.01	–
α-Copaene	1379	1374	0.37 ± 0.01	0.17 ± 0.01	0.22 ± 0.02	0.51 ± 0.03	0.24 ± 0.01
β-Elemene	1395	1389	4.34 ± 0.15	7.92 ± 0.20	7.88 ± 0.18	5.36 ± 0.18	7.81 ± 0.21
(*E*)-Caryophyllene	1424	1417	2.78 ± 0.02	1.84 ± 0.05	2.43 ± 0.05	2.80 ± 0.04	0.91 ± 0.02
β-Gurjunene	1433	1431	–	0.38 ± 0.02	–	–	0.15 ± 0.01
α-Guaiene	1442	1437	1.92 ± 0.02	0.79 ± 0.04	2.62 ± 0.06	2.37 ± 0.06	1.42 ± 0.03
α-Humulene	1458	1452	0.34 ± 0.01	0.47 ± 0.01	0.30 ± 0.02	0.62 ± 0.03	0.53 ± 0.02
γ-Muurolene	1486	1478	2.18 ± 0.03	1.92 ± 0.03	1.89 ± 0.04	1.42 ± 0.03	1.67 ± 0.04
Germacrene D	1489	1484	2.63 ± 0.03	0.60 ± 0.02	1.03 ± 0.03	0.77 ± 0.02	0.89 ± 0.03
α-Bulnesene	1510	1509	0.27 ± 0.01	0.31 ± 0.01	0.52 ± 0.01	0.40 ± 0.01	0.57 ± 0.02

Table 3. The end
Таблица 3. Окончание

Compound [a]	RI [b]	RI [c]	Treatments				
			T0	T1	T2	T3	T4
γ-Cadinene	1518	1513	0.12 ± 0.01	0.29 ± 0.01	0.37 ± 0.02	–	0.25 ± 0.01
δ-Cadinene	1526	1522	2.94 ± 0.03	0.45 ± 0.02	1.24 ± 0.04	2.27 ± 0.03	0.12 ± 0.01
(*E*)-Nerolidol	1563	1561	0.24 ± 0.02	0.32 ± 0.01	0.36 ± 0.01	0.13 ± 0.02	0.11 ± 0.01
Spathulenol	1582	1577	0.38 ± 0.01	0.25 ± 0.01	0.22 ± 0.01	0.17 ± 0.01	0.18 ± 0.01
1-*epi*-Cubenol	1632	1627	0.41 ± 0.02	0.61 ± 0.02	0.24 ± 0.02	0.11 ± 0.01	0.10 ± 0.01
epi-*α*-Cadinol	1645	1638	4.09 ± 0.08	4.17 ± 0.10	4.28 ± 0.09	6.30 ± 0.14	6.27 ± 0.13
Total identified (%)			94.34 ± 1.41	97.62 ± 1.78	96.46 ± 1.52	95.14 ± 1.69	97.87 ± 1.86

Note: [a] – elution order on an HP-5MS column; [b] – retention indices on an HP-5MS column; [c] – literature retention indices; [d] – not identified. **T0** – control, **T1** – chemical fertilizers, **T2** – cow manure, **T3** – chicken manure, and **T4** – chemical fertilizers + cow manure + chicken manure. Results are means of three measurements ± standard errors

Примечание: [a] – порядок элюирования на колонке HP-5MS; [b] – индексы удерживания на колонке HP-5MS; [c] – индексы удерживания из литературы; [d] – не определялось. **T0** – контроль, **T1** – химические удобрения, **T2** – коровий навоз, **T3** – куриный помет, **T4** – химические удобрения + коровий навоз + куриный помет. Результаты представлены как средние трех измерений ± стандартные ошибки среднего

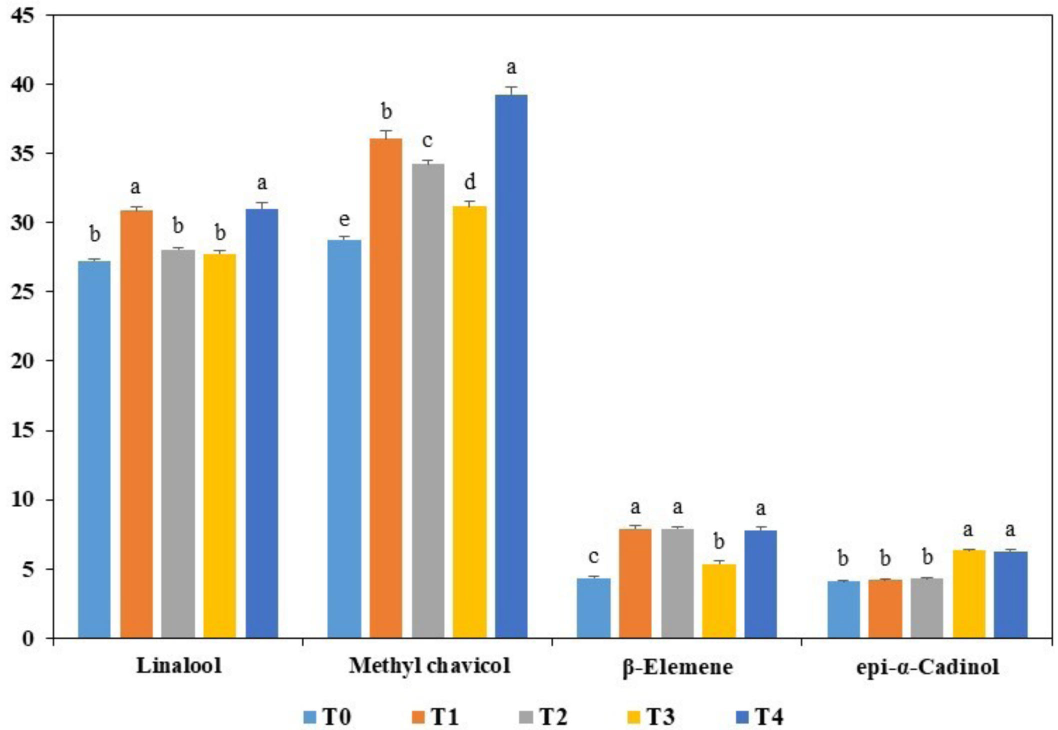

Fig. 2. **The effect of fertilizers on the content of main compounds (% of the total oil) in basil essential oil.** **T0** – control, **T1** – chemical fertilizers, **T2** – cow manure, **T3** – chicken manure, and **T4** – chemical fertilizers + cow manure + chicken manure. Results are means of three measurements ± standard errors. Values associated with different letters are significantly different according to Tukey's test at $p < 0.05$

Рис. 2. **Влияние удобрений на содержание основных компонентов (% суммы масел) эфирного масла базилика.** **T0** – контроль, **T1** – химические удобрения, **T2** – коровий навоз, **T3** – куриный помет, **T4** – химические удобрения + коровий навоз + куриный помет. Результаты представлены как средние трех измерений ± стандартные ошибки среднего. Значения, сопровождающиеся различными буквами, достоверно различаются по критерию Тьюки при $p < 0{,}05$

fertilizers on major compounds stems from the diverse minerals present in these combinations, which impact the secondary metabolism in plants (Bistgani et al., 2018; Keshavarz et al., 2018). These minerals contribute to an improvement in cellular metabolism and biomass production. Consequently, this results in enhanced vegetative growth and an increase in glandular trichomes (Said-Al Ahl et al., 2009; Bistgani et al., 2018; Yang et al., 2022).

Conclusions

In conclusion, the impact of fertilizer applications on basil cultivation was thoroughly examined in this study, revealing a significant effect on various growth and yield parameters. The use of fertilizers was found to positively affect plant height, number of lateral stems, fresh and dry yields, chlorophyll content, carotenoid content, essential oil yield, and essential oil content. Notably, the application of combined fertilizers demonstrated superior results in terms of growth, yield, and essential oil quality when compared to single fertilizer applications. Moreover, the chemical profile of basil essential oil obtained in this study closely resembled the profiles reported in previous research publications, indicating consistency in the essential oil composition.

The findings underscore the efficacy of employing a combination of chemical fertilizers, cow manure, and chicken manure for basil cultivation. This integrated fertilization approach was identified as the most suitable method for enhancing the economic productivity of basil crops. Overall, this study contributes valuable insights into optimizing fertilization practices for basil cultivation, providing a practical and effective strategy to boost both yield and essential oil quality.

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Information about the authors

Tong Van Giang, Dr. Sci. (Agriculture), Lecturer at the Faculty of Agriculture Forestry and Fisheries, Hong Duc University, 565 Quang Trung St., Thanh Hoa 40130, Vietnam, tongvangiang@hdu.edu.vn, https://orcid.org/0009-0000-8097-0717

Tran Thi Huyen, Dr. Sci. (Agriculture), Lecturer at the Faculty of Agriculture Forestry and Fisheries, Hong Duc University, 565 Quang Trung St., Thanh Hoa 40130, Vietnam, tranthuhuyen@hdu.edu.vn, https://orcid.org/0009-0006-3880-9544

Nguyen Huu Hai, Dr. Sci. (Agriculture), Researcher, Plant Resources Center, Vietnam Academy of Agricultural Sciences, Ha Noi 12500, Vietnam, haiprc1005@gmail.com, https://orcid.org/0009-0003-3042-1148

Информация об авторах

Тонг Ван Гианг, доктор сельскохозяйственных наук, преподаватель факультета сельского хозяйства, лесного хозяйства и рыболовства, Университет Хонг Дык, 40130 Вьетнам, Тхань Хоа, ул. Куанг Чунг, 565, tongvangiang@hdu.edu.vn, https://orcid.org/0009-0000-8097-0717

Чан Тхи Хуен, доктор сельскохозяйственных наук, преподаватель факультета сельского хозяйства, лесного хозяйства и рыболовства, Университет Хонг Дык, 40130 Вьетнам, Тхань Хоа, ул. Куанг Чунг, 565, tranthuhuyen@hdu.edu.vn, https://orcid.org/0009-0006-3880-9544

Нгуен Хуу Хай, доктор сельскохозяйственных наук, научный сотрудник, Центр растительных ресурсов Вьетнамской академии сельскохозяйственных наук, 12500 Вьетнам, Ханой, haiprc1005@gmail.com, https://orcid.org/0009-0003-3042-1148

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