How to cite: Tan, U., M. A. Kurt & O. Arabacı, 2023. Evaluation of different organic fertilizers for improving some agronomic characteristics and essential oil content of *Lippia citriodora* L.. Ege Univ. Ziraat Fak. Derg., 60 (3): 417-428, https://doi.org/10.20289/zfdergi.1289202

Research Article
(Araştırma Makalesi)

Ege Üniv. Ziraat Fak. Derg., 2023, 60 (3):417-428
https://doi.org/10.20289/zfdergi.1289202

Evaluation of different organic fertilizers for improving some agronomic characteristics and essential oil content of *Lippia citriodora* L.

Lippia citriodora L. bitkisinin bazı agronomik özellikleri ve uçucu yağ içeriğinin artırılması için çeşitli organik gübrelerin araştırılması

Uğur TAN [1*]
Mehmet Ali KURT [1]
Olcay ARABACI [1]

[1] Aydın Adnan Menderes University, Faculty of Agriculture, Department of Field Crops, 09970, Koçarlı, Aydın, Türkiye

* Corresponding author (Sorumlu yazar):
ugur.tan@adu.edu.tr

Received (Alınış): **05.05.2023** **Accepted** (Kabul Tarihi): **16.09.2023**

ABSTRACT

Objective: The objective of this was to identify the impact of various organic fertilizers on the yield and quality characteristics of *Lippia citriodora* L. plants and assess their adaptability under the ecological conditions of Aydın. Furthermore, it was also aimed to provide information on the potential of organic fertilizers to enhance crop productivity by minimizing the employment of chemical fertilizers.

Material and Methods: The study was conducted for two years (2018-2019) in Aydın ecological conditions. Six different organic fertilizers and one control were tested in the study, these are microbial fertilizer, animal-based liquid organic fertilizer, solid seaweed fertilizer, animal manure compost, leonardite and plant-based liquid organic fertilizer.

Research Findings: Organic fertilizers have a significant effect on all measured traits as compared to control, it may be due to biofertilizers can increase photosynthetic texture by increasing nitrogen, phosphorus and sulfur uptake, which these elements play an important role in chlorophyll production and required enzymes production. This can be the reason for obtaining positive effect of biofertilizers on plant growth and development.

Conclusion: Overall, findings suggest that the use of humic acid-containing fertilizers and proper organic fertilizer management can improve the growth and yield of *Lippia citriodora* L. plants.

Keywords: Agronomy, biofertilizer, essential oil, *Lippia*

ÖZ

Amaç: Bu çalışma, *Lippia citriodora* L. bitkisinin verim ve kalite özellikleri üzerinde çeşitli organik gübrelerin etkisini belirlemeyi ve Aydın ekolojik koşullarına uyumlarını değerlendirmeyi amaçlamıştır. Ayrıca araştırma bulguları, kimyasal gübre kullanımını en aza indirerek ürün verimliliğini artırmak için organik gübrelerin potansiyeline dair bilgi sağlamayı hedeflemiştir.

Materyal ve Yöntem: Çalışma Aydın ekolojik koşullarına iki yıl (2018-2019) süreyle yürütülmüştür. Çalışmada altı farklı organik gübre ve bir kontrol test edilmiştir, bunlar mikrobiyal gübre, hayvan bazlı sıvı organik gübre, katı deniz yosunu gübresi, hayvan gübresi, leonardit ve bitki bazlı sıvı organik gübredir.

Araştırma Bulguları: Organik gübreler, bitki büyümesi ve gelişimi üzerindeki olumlu etkisi, azot, fosfor ve kükürt alımını arttırarak fotosenteze katkı sağlaması ve bu elementlerin klorofil ve gerekli enzimlerin üretimi için önemli bir rol oynamaktadır. Organik gübreler, kontrol grubuna kıyasla tüm ölçülen özellikler bakımından önemli bir etkiye sahip olduğu saptanmıştır.

Sonuç: Bulgular, humik asit içeren gübrelerin kullanımı ve uygun organik gübre yöntemleri ile *Lippia citriodora* bitkilerinin büyüme ve verimini artırabileceğini göstermektedir.

Anahtar sözcükler: Agronomi, biyogübre, uçucu yağ, *Lippia*

.

INTRODUCTION

The utilization of chemical fertilizers in the agricultural sector has resulted in a conspicuous augmentation of crop productivity. Nonetheless, this particular practice has concurrently given rise to deleterious effects on enduring soil productivity and the inherent natural equilibrium (Tortopoğlu, 2000; Kendirli, 2010; Demir, 2021). Previous studies have demonstrated that chemical fertilizer applications to soil are only partially absorbed by plants, resulting in significant amounts of nitrogen and phosphorus leaching from crop fields and entering the atmosphere or drain water sources. This fact contributes to the generation of greenhouse gases, eutrophication in aquatic systems and soil salinization (Simpson et al., 2011; da Costa et al., 2013). In recent years, a growing societal awareness has emerged regarding the adverse impact of chemical fertilizers on the environment and human health. There is an increasing shift towards agricultural products cultivated through sustainable methods that uphold natural balances and avoid leaving toxic residues in the human body (Demir, 2021). Furthermore, organic fertilizers play a pivotal role in maintaining soil structure, conserving water, reducing soil erosion and preventing the depletion of natural resources. Moreover, it promotes the growth of beneficial soil organisms and maintains a healthy and diverse ecological system (Caris-Veyrat et al., 2004; Luthria et al., 2010; Vallverdú-Queralt et al., 2012; Oliveira et al., 2013). The utilization of organic fertilizers is especially vital for the cultivation of medicinal and aromatic plants in certified organic farming systems. These systems prohibit the use of synthetic fertilizers due to the detrimental effects as previously stated.

Medicinal and aromatic plants have various uses, either directly or indirectly, in the spice, tea, pharmaceutical and cosmetic industries, also they are gaining recognition in the scientific community due to their potential therapeutic properties. These plants are also utilized in the cosmetic industry for their refreshing fragrance. Aside from its use in the industry, *Lippia citriodora* leaves can be used to prepare phytotherapeutic teas that are known to offer various health benefits (Mosavi, 2012). These teas have a calming effect on the nervous system, which can help reduce anxiety and promote improved sleep (Amini et al., 2016).

The objective of this was to identify the impact of various brand organic fertilizers on the yield and quality characteristics of *Lippia citriodora* L. plants and assess their adaptability under the ecological conditions of Aydın. The research findings could provide insights into the potential of organic fertilizers to increase crop productivity while minimizing to use of chemical fertilization.

MATERIALS and METHODS

This study was conducted for two years in 2018 and 2019 at the experimental field of the Department of Field Crops, Faculty of Agriculture, Aydın Adnan Menderes University. Information about the materials and organic fertilizers used in the experiment is presented below.

Climatic features

Table 1 shows the average temperature and precipitation for Aydın/Koçarlı in 2018, 2019 and the long period. The data indicates that 2019 has generally higher temperature and precipitation values than 2018, with the exception of June and July which were much hotter in 2018. The yearly average temperature increased from 18.0°C to 19.0°C, while the yearly average precipitation increased from 514.7 mm to 618.6 mm however the precipitation (mm) values for both 2018 and 2019 was lower than long-period averages. Also, it can be seen that both 2018 and 2019 yearly average temperature (°C) values are higher than long-period temperature (°C).

Table 1. Average temperature and precipitation values of Aydın/Koçarlı in 2018, 2019 long period (1941-2022)

Çizelge 1. *Aydın/Koçarlı bölgesinin 2018, 2019 ve uzun dönem (1941-2022) ortalama sıcaklık ve yağış miktarları*

Aydın/Koçarlı	Average Temperature (°C)			Precipitation (mm)		
Months	**2018**	**2019**	**Long Period**	**2018**	**2019**	**Long Period**
January	7.7	8.5	8.1	84.8	206	118.9
February	11.2	10.6	9.4	71.4	58.3	92.3
March	13.8	13.3	11.7	39.6	28.6	70.6
April	18.3	16	16	5.2	56.9	47.5
May	22.4	21.6	20.9	34.8	11.9	35.9
June	18.5	26.9	25.6	0	26.9	16.4
July	34.2	28.5	28.3	0	1.2	7.5
August	28.6	29.3	27.7	8	0	5.7
September	31.6	24.4	23.7	18.2	16.6	17.3
October	17.1	21.4	18.6	32.4	29.4	43.5
November	8.8	16.5	13.5	127.3	65.1	81.7
December	4.2	10.5	9.5	93	117.7	122.6
Average	**18**	**19**	**17.7**	**514.7**	**618.6**	**659.9**

Meteorology (MGM), 2022.

Soil properties

Based on the results as tabulated in Table 2, it can be inferred that the soil has a strong alkaline nature, free from salinity and has a calcareous composition. The soil texture is clay loam, which is good for water retention and nutrient availability. The low organic matter content indicates that the soil may require additional nutrients for optimal plant growth. The phosphorus and potassium levels are also low, which may impact plant growth and development. However, the soil is rich in calcium and magnesium, which are essential nutrients for plant health.

Table 2. Soil analysis results of field of study

Çizelge 2. *Deneme alanının toprak analiz sonuçları*

pH	Salinity (**uS/cm)**	Lime (**%)**	Texture	Organic Matter (**%)**	Phosphorus (**ppm)**	Potassium (**ppm)**	Calcium (**ppm)**	Magnesium (**ppm)**
8.2	601	3.58	Clay Loam	1.51	6.9	130	4585	553
Strong Alkaline	Salinity-free	Calcareous	-	Low	Low	Low	High	Very High

Aydın, Department of Agriculture and Forestry, Soil Analysis Laboratory.

Material

Lemon Verbena (*Lippia citriodora* L.) belongs to the Verbenaceae family. Due to the difficulty of propagation through seeds, cuttings obtained from rootstock plants provided from the Bayındır district of İzmir. Cuttings were planted in bags prepared with peat and rooted through the process of vegetative propagation. After cuttings were rooted, these seedlings were planted in the field and measurements were obtained first and second year of plants.

Method

Field Experiment was designed as a randomized block design. with three replications. Each parcel in the experiment consisted of 4 rows, each 4 meters long and containing ten plants. There was a 1-meter distance between the parcels and a 2-meter distance between the blocks and the area of each parcel and the total field area was 6.4 m^2 (4m*1.6 m) and 380.8 m^2 (34 m x 11.2 m).

Seven different applications were tested, including microbial fertilizer, animal-based liquid organic fertilizer, solid seaweed fertilizer, animal manure compost, leonardite, plant-based liquid organic fertilizer, and control. The fertilizers were applied to the soil based on the description provided by the brand of product during the initial planting of the seedlings in the first year's spring and the second year's spring, the soil was re-fertilized once more. . Conventional methods were used as needed to avoid using herbicides in weed control. The doses of fertilizers applied are based on the recommended doses of the companies.

The following fertilizers were used in the study:

1. Microbial Fertilizer: Bontera brand microbial fertilizer was used. Its contents include *Bacillus amyloliquefaciens*, *Bacillus pumilus*, *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus megaterium*, *Trichoderma harzianum*, and *Trichoderma konigii*. Bacterial count: 1.2 x 10^8 CFU/mL. pH: 6-8.

2. Animal-based Liquid Organic Fertilizer: Colostrum brand fertilizer was used. Its contents are; Organic substance: 44%, Organic Carbon: 24%, Organic Nitrogen: 6.8%, Amino Acids: 14%, pH: 5.5-7.5.

3. Solid Seaweed Fertilizer: Sea farm brand fertilizer was used. Its contents include Organic substance: 45%, Potassium oxide: 5%, Alginic Acid: 2.5%, pH: 7-9.

4. Animal Manure Compost: Organic solid animal manure was used.

5. Leonardite: Perl humus brand was used. Its contents include Organic substance: 60%, Humic + Fulvic Acid: 60%, Maximum Moisture: 35%, pH Range: 5.5-7.5.

6. Plant-based Liquid Organic Fertilizer: Tekog brand was used. Its contents are; Total Organic substance: 40%, Organic Carbon: 18%, Total Nitrogen (N): 3%, Soluble Potassium K_2O: 4%, pH Range: 3.5-5.5. It also contains a certain amount of humic acid and more than 20 enzymes.

7. Control: No fertilizer applied.

In study, measurements of leaf length (cm), leaf width (cm) and plant height (cm) were taken from 10 randomly selected plants prior to harvest. Afterwards, the harvest of the plants in the parcels was carried out,excluding edge of parcel. The measurements obtained from the harvested plants were used to determine fresh herbage yield (kg/da), dry herbage yield (kg/da), fresh leaf ratio (%), fresh leaf yield (kg/da), dry leaf ratio (%), dry leaf yield (kg/da), essential oil content (%) (Wichtl, 1971), and essential oil yield (l/da).

Data Analysis

The obtained data were analyzed separately and differences were determined using the F-test. Variance analyses were performed using JMP Pro v.16 software. Statistically significant factors were grouped using the LSD (Least Significant Difference) test. Insignificant factors in the LSD test were compared based on mean tables.

RESULTS and DISCUSSION

The results of the analysis of variance of the data obtained from the measured parameters in this study are presented in Table 3. When the results were examined, it was determined that different organic fertilizers had a significant effect on leaf length (cm), plant height (cm), drog leaf yield (kg/da) and essential oil yield (l/da) at $^{**}P<0.01$ level according to 2018 (1st year) data. In addition, the effects of organic fertilizers on leaf width (cm), fresh herb yield (kg/ha), drog herb yield (kg/ha), dry leaf ratio (%) and essential oil content were found to be significant at $^{*}P<0.05$ level. The effects of organic fertilizers on fresh leaf ratio (%) and fresh leaf yield (kg/ha) were found to be insignificant.

When the results of 2019 (2nd year) in Table 3 were examined, it was determined that different organic fertilizers had a significant effect on leaf length (mm), leaf width (mm), plant height (cm), fresh leaf ratio (%), fresh leaf yield (kg/da), drog leaf yield (kg/da), essential oil content (%) and essential oil yield at a probability level of **P<0.01. In addition to this, the effects on the drog leaf ratio (%) were found to be significant at a probability level of *P<0.05, while the values of fresh herb yield (kg/ha) and drog leaf ratio (%) were affected insignificantly.

Table 3. Significance levels of F-values in variance analysis for various organic fertilizer applications on the *Lippia citriodora* plant

Çizelge 3. *Farklı organik gübre uygulamalarının Lippia citriodora bitkisi üzerine etkisine ilişkin varyans analiz sonucu F değerleri*

Parameters/Years	2018	2019
Leaf Length	18,5**	16,10**
Leaf Width	4,79*	25,85**
Plant Height	8,33**	88,03**
Fresh Herbage Yield	3,25*	2,76*
Drog Herb Yield	4,38*	3,73*
Fresh Leaf Eatio	0,89	6,86**
Fresh Leaf Yield	2,32	7,69**
Drog Leaf Ratio	4,07*	2,74
Drog Leaf Yield	5,23**	5,15**
Essential Oil Content	3,16*	5,86**
Essential Oil Yield	6,89**	6,47**

**P<0.01, *P<0.05 significance level.

Mean values and LSD groups for leaf length, leaf width and plant height are given in Table 4. When leaf length and width values were inspected, it can be stated that plant-based Liquid Organic fertilizers (PBF) and Leonardite (LEO) fertilizers had better values than other applications in 2019. This suggests that PBF and LEO fertilizers positively impacted leaf development, especially after the first year.

Moreover, the study revealed that different fertilizer applications affect plant height differently. While microbial fertilizer (MF) and animal-based liquid organic fertilizer (ABF) were more prominent in terms of plant height in 2018, PBF and LEO fertilizer applications were identified as the most effective in 2019 (Table 4). The results indicate that the impact of different fertilizer applications on plant height can vary depending vegetation year of the plant. Furthermore, when the effects of PBF and LEO fertilizers on leaf length, leaf width and plant height were evaluated, better results were obtained compared to other applications according to the results of this study.

Table 4. Effect of different organic fertilizer applications on *Lippia citriodora* plant's leaf length, leaf width and plant height

Çizelge 4. *Farklı organik gübre uygulamalarının Lippia citriodora bitkisinin yaprak uzunluğu, yaprak genişliği ve bitki boyu üzerine etkisi*

Fertilizers	Leaf Length (mm)		Leaf Width (mm)		Plant Height (cm)	
	2018	2019	2018	2019	2018	2019
MF	75.30 bc	82.67 b	14.93 bc	16.43 d	212.67 **a**	235.86 b
ABF	70.17 cd	76.53 c	15.37 b	18.10 c	209.67 **a**	227.38 bc
SF	74.03 bc	79.43 bc	16.20 **a**b	19.90 b	205.00 **a**b	225.00 c
AMC	77.83 b	81.33 bc	14.90 bc	20.17 b	191.59 b	228.33 bc
LEO	73.27 bc	94.73 **a**	15.60 **a**b	22.00 **a**	191.44 b	285.48 **a**
PBF	90.70 **a**	94.90 **a**	17.07 **a**	22.63 **a**	205.99 **a**b	290.48 **a**
C	65.50 d	83.67 b	13.73 c	15.77 d	164.38 c	222.62 c
Average	**75.26**	**84.75**	**15.40**	**19.29**	**197.25**	**245.02**
LSD	5.59	5.53	1.47	1.58	17.75	9.69

MF: Microbial fertilizer, ABF: Animal-based Liquid Organic Fertilizer, SF: Solid Seaweed Fertilizer, AMC: Animal Manure Compost, LEO: Leonardite, PBF: Plant-based Liquid Organic Fertilizer, C: Control.

Additionally, the study revealed that different fertilizer applications have varying effects on plant height. While microbial fertilizer (MF) and animal-based liquid organic fertilizer (ABF) were more prominent in terms of plant height in 2018, PBF and LEO fertilizer applications were identified as the most effective in 2019 (Table 4). The results indicate that the impact of different fertilizer applications on plant height can vary depending on the year.

According to Rajaraman & Pugalendhi (2013) humic acid including fertilizers can affect leaf nutrient content, including leaf nitrogen content, which can impact leaf size. Also, some other researchers stated that higher levels of nutrient availability in soil may lead to increased intake of micronutrients from the soil, resulting in increased nutrient contents in leaves (Samson & Visser, 1989; Adani et al., 1998). In our study, it is possible that fertilizer applications containing humic acid, such as PBF and LEO may have led to increased leaf characteristics such as leaf length and leaf weight as compared to other fertilizer applications. Yeshiwas (2017) and Deng et al. (2021) stated fertilizer applications can enhance the plant's photosynthetic capacity by increasing the leaf area and chlorophyll content. This means that more efficient and effective plant growth and overall increased yield. Özyilmaz et al. (2020) determined the average plant height of *L. citriodora* as 152.3 cm in their study. Elsayed et al. (2020) and Purbajanti et al. (2019) stated that both organic and inorganic fertilizers significantly improve plant growth, including plant height. Similarly, this study showed significant improvement in plant height with the use of organic fertilizers. In summary, these findings suggest that using humic acid-containing fertilizers and proper fertilizer management can improve the growth and yield of *L. citriodora* plants.

The results presented in Table 5 show the averages and LSD groups for fresh herbage yield (FHY), drog herbage yield (DHY) and fresh leaf ratio (FLR) of *L. citriodora* plant with different organic fertilizers. The findings indicate that plant-based liquid organic fertilizer (PBF) application resulted in the highest fresh herbage yield (FHY) values in both years and on the other hand, PBF and leonardite (LEO) fertilizers were found to have the highest values for drog herbage yield (DHY), separated from other fertilizer groups. These results suggest that PBF and LEO fertilizers are more effective on drog herb yield than other applications. Additionally, when the fresh leaf ratio (FLR) was examined, PBF, LEO, microbial fertilizer (MF), ABF, and AMC fertilizers were in the same LSD group in 2019, indicating that they were equally effective in improving the FLR trait.

Table 5. Effect of different organic fertilizer applications on *Lippia citriodora* plant's fresh herb yield, drog herb yield and fresh leaf ratio

Çizelge 5. *Farklı organik gübre uygulamalarının Lippia citriodora bitkisinin yeşil herba verimine, drog herba verimine ve yeşil yaprak oranına etkisi*

Fertilizers	**Fresh Herb Yield (kg/da)**		**Drog Herb Yield (kg/da)**		**Fresh Leaf Ratio (%)**	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**
MF	2007.29 **a**bc	3134.38 c	1271.16 ab	1431.04 b	55.33	49.67 **a**
ABF	1707.87 c	4866.41 **a**b	998.17 c	2236.72 **a**b	56.00	48.20 **a**b
SF	1983.24 **a**bc	3740.23 bc	1108.16 bc	1642.94 b	54.20	42.33 bc
AMC	1799.74 bc	3632.81 bc	1033.88 bc	1547.96 b	54.47	48.67 **a**b
LEO	2140.36 **a**b	4707.03 **a**b	1424.69 **a**	2548.45 **a**	55.07	54.33 **a**
PBF	2307.16 **a**	5304.69 **a**	1434.49 **a**	2829.57 **a**	55.67	54.53 **a**
C	1876.44 bc	3155.77 c	1133.72 bc	1524.49 b	56.27	40.33 c
Average	1974.59	4077.33	1200.61	1965.88	55.29	48.30
LSD	347.20	1328.53	260.40	896.21	7.85	6.33

MF: Microbial fertilizer, ABF: Animal-based Liquid Organic Fertilizer, SF: Solid Seaweed Fertilizer, AMC: Animal Manure Compost, LEO: Leonardite, PBF: Plant-based Liquid Organic Fertilizer, C: Control.

Karik & Azkan (2011)'s study determined that *L. citriodora* produced between 486.2-1075.7 kg/da of fresh herbage yield in the first year and 830.7-1458.0 kg/da in the second year. The dry herbage yield ranged between 196.0-433.8 kg/da in the first year and 337.8-610.2 kg/da in the second year. In a different study, Rode (1997) reported 284.0-713.75 kg/da fresh herbage yield for *L. citriodora*. In our study, we found that the fresh herbage yield was between 1707 and 2307 kg/da in the first year and 3134 to 5304 kg/da in the second year, while the drog herbage yield was 998 to 1434 kg/da in the first year and 1431 to 2829 kg/da in the second year.

The study by Karik & Azkan (2011) provides information regarding the fresh and dry herbage yields of *L. citriodora* over two consecutive years. The results of their study show that the fresh herbage yield of *L. citriodora* was higher in the second year than in the first year, this indicating that the plant may require more time to reach its maximum yield potential due to it is a perennial type plant. Moreover, the wide range of fresh and dry herbage yield values observed in their study suggests that the yield performance of *L. citriodora* can be influenced by various factors, such as soil conditions, environmental conditions, and management practices. The main factor for a wide range of yield values were different planting density for their study.

According to Gharib et al. (2008), biofertilizer treatments increase the fresh and dry weight of herbs as compared to the control. Organic fertilizers have beneficial effects on plant growth and development. They make soil nutrients biologically available to plants, produce plant hormones, affect plant metabolism, and control harmful pathogens (Ping & Boland, 2004).

Can & Katar (2020) investigated the effects of different organic fertilizers (Lifebac-Np, Bactoguard, Humica Power) on the fresh herbs yield in *Mentha spicata* and *Mentha x piperita* species. The researchers reported that the organic fertilizers did not show a significant difference in fresh herb yield. However, there were differences between years and this was attributed to climatic factors by the researchers.

The findings from Rode (1997)'s study on *L. citriodora* are consistent with Karik & Azkan's (2011) study in terms of the range of fresh herbage yield values. The fresh herbage yields reported in our study are considerably higher than those reported by Rode (1997) and Karik & Azkan (2011). This could be attributed to differences in the growing conditions, management practices or genetic variability of the plant material used in these studies. Can & Katar (2020) found that Lifebac-Np fertilizer containing *Bacillus* group bacteria was more effective on fresh herb and dry herb yields than Humica Power fertilizer containing humic/fulvic acid. Also, researchers indicated that It can be explained by the ability of *Bacillus* spp. bacteria in microbial fertilizer to synthesize phytohormones such as auxin and cytokinin (Castanheira et al., 2013). However, according to the results of this study it is seen that LEO and PBF fertilizers containing humic/fulvic acid are more effective on fresh herb and dry herb yields, MF fertilizer containing *Bacillus* group bacteria was effective on fresh herb yield in 2018, and other than that, fertilizers containing humic/fulvic acid were found to be more effective. This difference may be due to the fact that the studied plants were different.

Several hypotheses have been proposed regarding the effects of humic substances, their involvement in improving enzyme catalysis, their influence in stimulating respiration, photosynthesis and nucleic acid metabolism, and their hormonal activity (Muscolo et al., 1999; Nardi et al., 2002).

Overall, this results contributes valuable insights into the use of organic fertilizers, especially PBF and LEO, as effective tools for enhancing the growth and yield of *L. citriodora* plants. However, further research is recommended to explore the underlying mechanisms behind these fertilizers' effects and better understand the potential variations in plant responses under different environmental conditions and plant varieties. These results provide valuable insights into the yield potential of *L. citriodora*, which can be useful for farmers and researchers interested in cultivating and studying this plant species.

The mean values and LSD groups for fresh leaf yield (FLY), frog leaf ratio (%) and drog leaf yield (kg/da) are tabulated Table 6. The numerically highest values for DLR and DLY were obtained from LEO fertilizer in the first year (2018), while the numerically highest values were obtained from PBF fertilizer in second year (2019). FLY (kg/da) has reached the numerically highest value for PBF in the first year, while both PBF and LEO fertilizers produced the numerically highest values in the second year. According to these results, differences between the two years are noticeable. This could be due to the first year was growth stage of plant. While these results were also evident in the previously mentioned for yield parameters like DLY and numerically FLY and DLR were affected more prominently with PBF and LEO fertilizers in both years. This could be due to the effect of different forms of fertilizers.

Table 6. Effect of different organic fertilizer applications on *Lippia citriodora* plant's fresh leaf yield, drog leaf ratio and drog leaf yield

Çizelge 6. *Farklı organik gübre uygulamalarının Lippia citriodora. bitkisinin yeşil yaprak verimi, kuru yaprak oranı ve kuru yaprak verimi üzerine etkisi*

Fertilizers	**Fresh Leaf Yield (kg/da)**		**Drog Leaf Ratio (%)**		**Drog Leaf Yield (kg/da)**	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**
MF	1116.75 **a**b	1542.75 c	47.08 bc	46.79 **a**bc	609.10 bc	665.32 c
ABF	951.54 b	2346.23 **a**b	42.89 c	44.25 bc	426.93 c	994.48 bc
SF	1070.97 **a**b	1632.10 c	46.25 bc	46.18 **a**bc	526.29 c	751.42 c
AMC	972.88 b	1746.88 bc	45.98 bc	46.49 **a**bc	480.32 c	713.54 c
LEO	1176.75 **a**b	2565.04 **a**	58.05 **a**	50.41 **a**b	825.98 **a**	1274.27 **a**b
PBF	1294.89 **a**	2895.03 **a**	50.50 b	52.33 **a**	726.17 **a**b	1483.75 **a**
C	1056.42 **a**b	1353.71 c	46.06 bc	42.81 c	522.20 c	652.06 c
Average	1091.46	2011.68	48.11	47.04	588.14	933.55
LSD	239.13	648.83	7.46	6.14	191.15	444.85

MF: Microbial fertilizer, ABF: Animal-based Liquid Organic Fertilizer, SF: Solid Seaweed Fertilizer, AMC: Animal Manure Compost, LEO: Leonardite, PBF: Plant-based Liquid Organic Fertilizer, C: Control.

Karik & Azkan (2011) reported drog leaf yields of 212.5 kg/da in the first year and 271.3 kg/da in the second year. Rode (1997) found that drog leaf yields ranged between 42.6-118.1 kg/da, while Özyilmaz et al. (2020) determined fresh leaf yields of 553.6 kg/da and drog leaf yields of 83.8 kg/da. Mohammadi et al. (2013a) reported that the control groups' fresh and dry leaf weights were 322.8 kg/da and 151.3 kg/da, respectively. They also reported that fresh leaf yield increased up to 636.4 kg/da and drog leaf yield up to 307.5 kg/da in plots where fertilization was applied.

According to Solmaz et al. (2018) study, increasing doses of leonardite application were determined to increase yield in the dry matter of plants. Purwanto et al. (2021) suggested that humic substances increase crop P uptake since they can compete with P to be bound to soil adsorption complexes. In agreement with this, Kaya et al. (2020) observed that leonardite enhanced leaf P and yield in maize under water stress in calcareous soils.

According to Abdel-Baky et al. (2019) fulvic acid fertilizers significantly promote vegetative growth and dry matter production by increasing the development of shoots and roots, increasing leaf area, and Chl. accumulation. Promoting root growth enhances the capacity to uptake and utilize nutrients from the soil making higher dry matter accumulation.

Esringü et al. (2015)'s study results showed that treatments of HA (40 mg kg^{-1}) and FA (40 mg kg^{-1}) enhanced the growth significantly when compared to the control groups. This result shows the promoting effects of HA and FA on plant growth parameters as the number of buds, plant height, number of main shoots, number of side shoots, plant diameter, root length, fresh root weight, dry root weight, fresh shoot weight and dry shoot weight. The Results obtained by Mohammadi et al. (2013b) indicated that biological fertilizers had significant effects because biological fertilizers increase the photosynthesis tissue amount with help of nitrogen, phosphorus and sulfur absorption which have effects on Chlorophyll production and plant enzyme production.

By regarding these results, the use of biological fertilizers had positive effects on the improving growth of *Lippia citiodora* plant. Biological fertilizers have undeniable importance in soil fertility, particularly in sandy soils with low organic matter content. Also increases leaf microelement values and nutrient-rich and slow-release organic fertilizers contribute to productivity for a long time as found by Yoldas et al. (2009), Mordogan et al. (2017).

Table 7 compares the essential oil content (EOC) and essential oil yield (EOY) of different fertilizers over two years. In the first year, LEO fertilizer resulted in numerically the highest EOY values, while MF fertilizer led to numerically the highest EOC values. The EOC values for this year ranged between 0.42% to 0.61%. This indicates that the use of LEO, MF and SF fertilizers could be beneficial for increasing the overall quality of essential oils in the first year.

Table 7. Effect of different organic fertilizer applications on *Lippia citriodora* plant's essential oil content and essential oil yield.

Çizelge 7. *Farklı organik gübre uygulamalarının Lippia citriodora bitkisinin uçucu yağ içeriğine ve uçucu yağ verimine etkisi.*

Fertilizers	**Essential Oil Content (%)**		**Essential Oil Yield (l/da)**	
	2018	**2019**	**2018**	**2019**
MF	0.61 **a**	0.63 c	3.83 **a**b	4.09 b
ABF	0.43 bc	0.53 c	1.81 d	5.31 b
SF	0.54 **a**bc	0.48 c	2.86 bcd	3.55 b
AMC	0.43 bc	0.67 bc	2.01 cd	4.86 b
LEO	0.56 **a**b	0.87 **a**b	4.56 **a**	11.45 **a**
PBF	0.42 c	0.88 **a**	3.11 bc	13.22 **a**
C	0.46 bc	0.50 c	2.41 cd	3.26 b
Average	0.49	0.65	2.94	6.53
LSD	1.32	2.12	1.15	4.88

MF: Microbial fertilizer, ABF: Animal-based Liquid Organic Fertilizer, SF: Solid Seaweed Fertilizer, AMC: Animal Manure Compost, LEO: Leonardite, PBF: Plant-based Liquid Organic Fertilizer, C: Control.

In the second year, PBF and LEO fertilizers resulted in the highest EOY values, forming a separate group from other fertilizers. This implies that these fertilizers may be more effective in increasing the essential oil yield in the second year. From a statistical perspective, the highest EOC values in the second year were observed using PBF and LEO fertilizer, with a range of 0.53% to 0.88%.

These findings suggest that different fertilizers have varying effects on the quality characteristics of essential oils over time. LEO appears to be a consistent choice for increasing EOY values, MF-LEO-SF and PBF-LEO fertilizers seem to be more effective at improving EOC values in the first and second years, respectively. Further research may be needed to optimize the use of these fertilizers for different crops and conditions.

Can & Katar (2020) reported that the average organic fertilizer applications in *Mentha spicata* species were higher in 2019 (1.97%) as compared to 2018 (1.80%). Organic fertilizer applications did not have a significant effect on the essential oil ratio in both mint species, however, the highest essential oil ratio was determined in the Lifebac-Np application with 1.94% in *Mentha spicata* and in the Humica Power application with 2.24% in *Mentha x piperita.*

Studies on the subject reported that organic fertilizer significantly increased the essential oil ratio in *Mentha* species (Mahboobeh et al., 2014; Sheykholeslami & Almdari, 2019). This can be explained by the differences in the content, dosage and application method of organic fertilizers used in the studies. Similarly, Keshavarz and Sanavy (2018) reported that the essential oil ratio did not change significantly with organic fertilizer application. Alsafar & Al-Hassan (2009) stated that as the growth rate increased with increasing fertilization, the essential oil yield also increased. Similar to oil percentage, essential oil yield was also improved by 13% related to control when treatment was applied.

Rasouli et al. (2022) found that different fertilizers combined with HA (humic acid) fertilization increased EOC up to 30-37% as compared to control. The highest EOC was obtained with chemical fertilizer × HA (0.248%) and chemical fertilizer × without HA (0.244%). The least EOC was recorded in the control (0.181%).

For essential oil yield (EOY), Rasouli et al. (2022) suggest that HA and their combinations were significant on the EOY. Chemical fertilizer × without HA and chemical fertilizer × HA led to the highest EOY (0.720 g m^{-2} and 0.692 g m^{-2} respectively). While the least EOY was recorded in control with 0.288 g m^{-2}. The application of various fertilizers and HA improved EOY up to 132-150% over the control.

Karik & Azkan (2011) reported EOC and EOY values of 0.90% for both the first and second years. Shahhoseini et al. (2018) found EOC as 1.77% and 17.11 l/da for EOY. Özyilmaz et al. (2020) reported EOC as 0.30%, while Rode (1997) found EOC values between 0.50-0.54% and EOY values between 0.4-1.2 l/da. Ateia et al. (2009) concluded that plants can benefit from the application of specific organic fertilizers for improving growth, yield, and essential oil constituents. This finding highlights the significance of organic farming practices in promoting sustainable agriculture and providing clean and high-quality agricultural products. According to Shahhoseini et al. (2018) EOC and EOY of lemon verbena were significantly improved by fertilizer treatments.

This and other studies demonstrated the potential benefits of using appropriate fertilizers to enhance the quality characteristics of essential oils in plants. Different fertilizers show varying effects, so further research is needed to optimize fertilizer use for different crops and conditions.

As results indicated before, bio-fertilizers had a significant effect on all measured traits compared to control, it may due to biofertilizers can increase photosynthetic texture by increasing nitrogen, phosphorus and sulfur uptake, which these elements play an important role in chlorophyll production and required enzymes production. This can be the reason for positive effect of biofertilizers on plant growth and development.

CONCLUSIONS

In this study, the impact of various organic fertilizers on the growth and yield of *L. citriodora* plants was investigated over a period of two years. The objective of the experiment was to determine the effectiveness of different organic fertilizers sold by different companies for enhancing growth and yield characteristics of cultivated plants. The results demonstrated that the effects of different organic fertilizers were not uniform across all aspects of plant growth and yield.

Two organic fertilizers, Plant-based Liquid Organic Fertilizer (PBF) and Leonardite (LEO) were found to be particularly beneficial for improving leaf traits, such as leaf length, width and overall plant height. These fertilizers promoted the growth of larger leaves, which is essential for the commercial value of *L. citriodora* plants. Furthermore, PBF and LEO fertilizers proved to be more effective in enhancing the drog herb yield when compared to other applications tested in this study.

In addition to PBF and LEO fertilizers, the research also highlighted the efficacy of microbial fertilizer (MF) in improving the fresh leaf ratio (FLR) trait. It was found that PBF, LEO, MF, ABF and AMC fertilizers were equally effective in promoting a higher FLR, which is a crucial factor in determining the overall quality of the *L. citriodora* plants.

Overall, these findings suggest that the use of humic acid-containing fertilizers and proper organic fertilizer management can improve the growth and yield of *L. citriodora* plants.

REFERENCES

Abdel-Baky, Y. R., H. F. Abouziena, A. A. Amin, M. Rashad El-Sh & A. E. S. Am, 2019. Improve quality and productivity of some faba bean cultivars with foliar application of fulvic acid. Bulletin of the National Research Centre, 43 (1): 1-11. https://doi.org/10.1186/s42269-018-0040-3

Alsafar, M. S. & Y. M. Al-Hassan, 2009. Effect of nitrogen and phosphorus fertilizers on growth and oil yield of indigenous mint (*Mentha longifolia* L.). Biotechnology (Faisalabad), 8 (3): 380-384. https://doi.org/10.3923/biotech.2009.380.384

Amini, F., G. R. Asghari, S. M. Talebi, M. Askary & M. Shahbazi, 2016. Effect of environmental factors on the compounds of the essential oil of *Lippia citriodora*. Biologija, 62 (3): 194-201. https://doi.org/10.6001/biologija.v62i3.3372

Ateia, E. M., Y. A. H. Osman & A. E. A. H. Meawad, 2009. Effect of organic fertilization on yield and active constituents of *Thymus vulgaris* L. under North Sinai conditions. Research Journal of Agriculture and Biological Sciences, 5 (4): 555-565.

Can, M. & D. Katar, 2020. Mentha x piperita L. ve *Mentha spicata* L. türlerinde yapraktan uygulanan farklı organik gübrelerin tarımsal ve kalite özelliklerine etkisi. Anadolu Journal of Agricultural Sciences, 35 (3): 361-373. https://doi.org/10.7161/omuanajas.747347

Caris-Veyrat, C., M. J. Amiot, V. Tyssandier, D. Grasselly, M. Buret, M. Mikolajczak, J. C. Guilland, C. Bouteloup-Demange & P. Borel, 2004. Influence of organic versus conventional agricultural practice on the antioxidant microconstituent content of tomatoes and derived purees; consequences on antioxidant plasma status in humans. Journal of Agricultural and Food Chemistry, 52 (21): 6503-6509. https://doi.org/10.1021/jf0346861

Castanheira, N., A. C. Dourado, P. I. Alves, A. M. Cortes-Pallero, A. I. Delgado-Rodriguez, A. Prazeres ... & P. Fareleira, 2014. Annual ryegrass-associated bacteria with potential for plant growth promotion. Microbiological Research, 169 (9-10): 768-779. https://doi.org/10.1016/j.micres.2013.12.010

da Costa, P. B., A. Beneduzi, R. de Souza, R. Schoenfeld, L. K. Vargas & L. M. P. Passaglia, 2013. The effects of different fertilization conditions on bacterial plant growth promoting traits: Guidelines for directed bacterial prospection and testing. Plant and Soil, 368 (1): 267-280. https://doi.org/10.1007/s11104-012-1513-z

Demir, E., 2021. Diyarbakir Ekolojik Koşullarinda Nohut (*Cicer arietinum* L.)' da Kimyasal ve Organik Gübrelemenin Verim ve Verim Özelliklerine Etkisi. Graduate School of Education, Mardin Artuklu University (Unpublished) Master Thesis, Mardin, 78 pp.

Deng, F., L. Wu, L. Wang, H. Hui, L. Shuang, S. L. Pu, T. Youfeng, G. H. Li & W. J. Ren, 2020. Effect of controlled-release fertilizers on leaf characteristics, grain yield, and nitrogen use efficiency of machine-transplanted rice in southwest China. Archives of Agronomy and Soil Science, 67 (13): 1739-1753. https://doi.org/10.1080/03650340.2020.1807519

Elsayed, S. I. M., A. A. Glala, A. M. Abdalla, A. E. G. A. El-Sayed, & M. A. Darwish, 2020. Effect of biofertilizer and organic fertilization on growth, nutrient contents and fresh yield of dill (*Anethum graveolens*). Bulletin of the National Research Centre, 44 (1): 1-10. https://doi.org/10.1186/s42269-020-00375-z

Esringü, A., I. Sezen, B., Aytatlı & S. Ercişli, 2015. Effect of humic and fulvic acid application on growth parameters in Impatiens walleriana L. Akademik Ziraat Dergisi, 4 (1): 37-42.

Gharib, F. A., L. A. Moussa & O. N. Massoud, 2008. Effect of compost and bio-fertilizers on growth, yield and essential oil of sweet marjoram (*Majorana hortensis*) plant. International Journal of Agriculture and Biology, 10 (4): 381-387.

Karik, Ü. & N. Azkan, 2011. The effect of different planting spacings on drug herb essential oil yield and the quality of essential oil in lemon verbena (*Lippia citriodora* L.). Bahçe, 40 (1): 23-34.

Kaya, C., M. Şenbayram, N. A. Akram, M. Ashraf, M. N., Alyemeni & P. Ahmad, 2020. Sulfur-enriched leonardite and humic acid soil amendments enhance tolerance to drought and phosphorus deficiency stress in maize (*Zea mays* L.). Scientific reports, 10 (1): 6432. https://doi.org/10.1038/s41598-020-62669-6

Kendirli, K., 2010. Spirulina Kültürlerinde Besin Elementlerinin Farklı Oranlarda Kullanımının Kuru Madde, Protein ve Klorofil-a Düzeyine Etkisi. Graduate School of Natural and Applied Sciences, Çukurova University (Unpublished) Master Thesis, Adana, 92 pp.

Keshavarz, H. & S. A. M. M. Sanavy, 2018. Yield and oil content of mint under different nitrogen fertilizer treatments. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 10 (1): 92-96. https://doi.org/10.15835/nsb10110221

Luthria, D. L., A. P. Singh, T. Wilson, N. Vorsa, G. S. Bañuelos & B. T. Vinyard, 2010. Influence of conventional and organic agricultural practices on the phenolic content in eggplant pulp: Plant-to-plant variation. Food Chemistry, 121 (2): 406-411. https://doi.org/10.1016/j.foodchem.2009.12.055

Mahboobeh, Z., A. S. Morteza, T. Mryam & S. A. Reza, 2014. Effects of organic and chemical fertilizers on quantitative and qualitative characteristics of peppermint (*Mentha piperita* L.). International Journal of Agriculture and Crop Sciences (IJACS), 7 (5): 237-244.

Mohammadi, M., A. Tobeh, R. Fakhari, H. Naghdi & M. Ochi, 2013a. The quantitative yield of lemon verbena (*Lippia citriodora*) as influenced by different biological fertilizers. International Journal of Agronomy and Plant Production, 4 (9): 2126-2129.

Mohammadi, M., A. Tobeh, H. Naghdi, M. O. Ardabili & S. Rezazade, 2013b. The biological fertilizers effects on the quality yield of *Lippia citriodora* plant. International Journal of Agronomy and Plant Production, 4 (5): 1006-1012.

Mordogan, N. S. & S. Ceylan, 2017. Organik gübrelemenin kumlu tın bünyeli toprakta yetişen zeytin ağaçlarının verim ve mikro element içeriğine etkisi. Ege Üniversitesi Ziraat Fakültesi Dergisi, 54 (4): 413-419. https://doi.org/10.20289/zfdergi.386470

Mosavi, A. A., 2012. The optimization of lemon verbena (*Lippia citriodora*) medicinal plant tissue culture. International Journal of Agronomy and Plant Production, 3 (11): 561-565.

Muscolo, A., F. Bovalo, F. Gionfriddo & S. Nardi, 1999. Earthworm humic matter produces auxin-like effects on *Daucus carota* cell growth and nitrate metabolism. Soil Biology & Biochemistry, 31 (9): 1303-1311. https://doi.org/10.1016/s0038-0717 (99)00049-8

Nardi, S., D. A. Pizzeghello, A. Muscolo & A. Vianello, 2002. Physiological effects of humic substances on higher plants. Soil Biology & Biochemistry, 34 (11): 1527-1536. https://doi.org/10.1016/s0038-0717 (02)00174-8

Oliveira, A. B., C. F. H. Moura, E. Gomes-Filho, C. A. Marco, L. Urban & M. R. A. de Miranda, 2013. The impact of organic farming on quality of tomatoes is associated to increased oxidative stress during fruit development. PLOS ONE, 8 (2). https://doi.org/10.1371/journal.pone.0056354

Özyilmaz, B., G. Yilmaz, Ö. Koyutürk, R. Karataş, L. Yazici & K. Astan, 2020. Tokat ekolojik koşullarında *Lippia citriodora'*nın uygun dikim sıklığı ve yetiştirilme potansiyelinin belirlenmesi. Ziraat Fakültesi Dergisi, Special Issue: 166-171.

Ping, L. & W. Boland, 2004. Signals from the underground: Bacterial volatiles promote growth in Arabidopsis. Trends in Plant Science, 9 (6): 263-266. https://doi.org/10.1016/j.tplants.2004.04.008

Purbajanti, E. D., W. Slamet, E. Fuskhah & R. Rosyida, 2019. "Effects of organic and inorganic fertilizers on growth, activity of nitrate reductase and chlorophyll contents of peanuts (*Arachis hypogaea* L.)." International Conference on Sustainable Agriculture for Rural Development (ICSARD 2018, 23-24 October 2018, Purwokerto, Indonesia), IOP Conf. Ser: Earth Environ. Sci. 250 (1): article no: 012048.

Purwanto, B. H., P. Wulandari, E. Sulistyaningsih, S. N. Utami & S. Handayani, 2021. Improved corn yields when humic acid extracted from composted manure is applied to acid soils with phosphorus fertilizer. Applied and Environmental Soil Science, Volume 2021: 1-12. https://doi.org/10.1155/2021/8838420

Rajaraman, G. & L. Pugalendhi, 2013. Influence of spacing and fertilizer levels on the leaf nutrient contents of Bhendi (*Abelmoschus esculentus* L. Moench) under drip fertigation system. African Journal of Agricultural Research, 8 (48): 6344-6350.

Rasouli, F., Y. Nasiri, M. Asadi, M. B. Hassanpouraghdam, S. Golestaneh & Y. Pirsarandib, 2022. Fertilizer type and humic acid improve the growth responses, nutrient uptake, and essential oil content on *Coriandrum sativum* L. Scientific Reports, 12 (1): 7437.

Shahhoseini, R., K. Saeidi, H. Babaahmadi & M. T. Ebadi, 2018. Effect of fertilizers and superabsorbent hydrogel on the yield, essential oil content and composition of lemon verbena (*Lippia citriodora* Kunth.) cultivated in Iran. Journal of Essential Oil Bearing Plants, 21 (1): 230-236. https://doi.org/10.1080/0972060x.2017.1422808

Sheykholeslami, Z. & M. Q. Almdari, 2019. Comparison of the effect of organic and chemical fertilizers on yield and essence of peppermint (*Mentha piperita* L.). Current Journal of Applied Science and Technology, 34 (5): 1-7.

Simpson, R. J., A. Oberson, R. A. Culvenor, M. H. Ryan, E. J. Veneklaas, H. Lambers ... & A. E. Richardson 2011. Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. Plant and Soil, 349 (1): 89-120. https://doi.org/10.1007/s11104-011-0880-1

Solmaz, A., K. Bellitürk, A. Adiloğlu & S. Adiloglu, 2018. The Effect of increasing leonardit applications on dry matter yield and some nutrient elements contents of rye (*Secale cerale* L.) plant. Journal of Forest Science, 6 (1): 44-51.

Tortopoğlu, A. P., 2000. Ekolojik Tarım ve Geleceği. Hasat yayıncılık, Ankara, 182 s.

Vallverdú-Queralt, A., A. Medina-Remón, I. Casals-Ribes & R. M. Lamuela-Raventós, 2012. Is there any difference between the phenolic content of organic and conventional tomato juices. Food Chemistry, 130 (1): 222-227. https://doi.org/10.1016/j.foodchem.2011.07.017

Wichtl, M., 1971. Die fharmakognostisch-Chemische Analyse. Gehaltsbestim,mung von Drogen (und Zubereitungen) mit atherischem 01, Akadem. Yayıncılık, Frankfurt, 263-281.

Ye, L., X. Zhao, E. Bao, J. Li, Z. Zou & K. Cao, 2020. Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. Scientific Reports, 10 (1): 177-177. https://doi.org/10.1038/s41598-019-56954-2

Yeshiwas, Y., 2017. Effect of different rate of nitrogen fertilizer on the growth and yield of cabbage (*Brassica Oleraceae*) at Debre Markos, North West Ethiopia. African Journal of Plant Science, 11 (7): 276-281. https://doi.org/10.5897/ajps2015.1330

Yoldaş, F., S. Ceylan & Ö. L. Elmaci, 2009. Organik ve kimyasal gübrelemenin sanayi domatesinde (*Lycopersicon lycopersicum* L.) verim, bazı kalite özellikleri ve besin element içeriği üzerine etkisi. Ege Üniversitesi Ziraat Fakültesi Dergisi, 46 (3): 191-197.