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Monitoring essential oil yields from lavender (Sevopolis variety) extracted via steam and hydrodistillation

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Abstract

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The purpose of this publication was to monitor the amount of essential oil extracted from the Lavender variety Sevtopolis by two methods – Clevenger hydrodistillation and steam distillation. The research was conducted in 2021 and 2022 in an experimental field located in the Chirpan region of central Bulgaria (42°07′33″N 25°23′03″E, 147 m). Lavender plants were randomly selected from the experimental field which was divided into five plots fertilized differently with an organic biostimulant "Atlas Universal" as follows: 30, 50, 80, and 100 ml of fertilizer per plot (35 m^2). One plot was left untreated as a control field. Univariate ANOVA analysis with a Post Hoc Games-Howell test was conducted to determine significant differences in the amount of essential oil extracted using both methods. Correlation analysis was used to assess the relationship between the amount of organic fertilizer used and the quantity of extracted essential oil, while regression analysis was used to create predictive models – Linear and Quadratic. The highest amounts of essential oil were obtained through steam distillation (1.677 ml for 2021 and 2.310 ml for 2022) from Field I, which was treated with 30 ml of organic fertilizer. The calculated coefficients of determination for the two distillation methods (R^2 = 0.627; 0.660 for 2021 and R^2 = 0.827; 0.829 for 2022) indicate that the Quadratic model is more suitable for describing the relationship between the amount of organic fertilizer and the amount of extracted essential oil. The high coefficients of determination (0.977 and 0.944) obtained from Field I when comparing the two distillation methods indicate that fertilizing with 30 ml of organic fertilizer per plot is the most suitable. Based on these findings, the research team recommends using the steam distillation method for extracting lavender oil.

Keywords: essential oil; steam distillation; hydrodistillation; fertilizing lavender; organic biostimulant; yield

Introduction

Bulgaria grows many plant species that contain volatile chemical compounds, which can be extracted as essential oils. These oils are extracted from various parts of the plant, such as the flowers, bark, stem, leaves, roots, and fruits (Ali et al., 2015). Different methods are used in laboratories and industries to separate these essential oils (Cassel et al., 2009; Hristova & Veleva, 2022). Authors like Radwan et al. (2020) and Afzal et al. (2017) utilize solar energy to extract volatile oils from medicinal and aromatic plants. The solar distillation system they use consists of a primary reflector (Scheffler concentrator), a vapor receiver, a distillation still, a condenser, and a Florentine flask (Afzal et al., 2017; Radwan et al., 2020). This system was developed for the production of essential oils through water-steam distillation. Akterian et al. (2014) developed a periodically operating distillation apparatus with a built-in steam generator that works with electric resistance heaters and thermal mineral oil as an intermediate heat carrier for processing raw essential oil materials.

In Bulgaria, the most cultivated essential oil crop is lavender. The essential oil extracted from it has a significant contribution to the international market, mainly as an additive for the production of food, perfume and pharmaceutical products

(Kim & Lee, 2002; Cassel et al., 2009; Zheljazkov et al., 2012; Li et al., 2014). Regardless of the low purchase price of lavender oil in recent years, lavender production is still significant for Bulgaria. The Bulgarian varieties Sevtopolis, Hemus, Druzhba, Raya and Yubileyna, which were created at the Institute of Rose and Essential Cultures in Kazanlak, have priority in the economic importance (Slavova & Ducheva, 2018). The climate conditions in the individual regions of the country and the good agricultural practices of the farmers are an important factor in obtaining high yields and quality lavender oil. Aiming to reduce the risks to the environment, modern agriculture is trying to alter crops in a more sustainable way. Lavender plants are grown under a nutritional regimen formed by natural fertility and supplemented with nutrients introduced foliarly or through the soil – biostimulants, organic fertilizers, compost, soil boosters of organic origin. Biostimulants used in agriculture are able to stimulate plant nutrition processes by increasing the efficiency of nutrient use, to increase tolerance to abiotic stress and to improve the quality of production. These products are based on natural raw materials, such as hydrolyzed proteins and amino acids from animal and plant by-products, microalgae and seaweed extracts, humic acids, plant extracts and microorganisms (Caccialupi et al., 2022). The great variety of biostimulants enables many researchers to trace their influence on different crops. The application of biostimulants in lavender plantations has a positive effect on plant height, number of branches per tuft, flower and essential oil yield, crude protein content, total pigment, antioxidant, flavonoid, phenol, total carbohydrates, and free amino acid content (Giannoulis et al., 2020; Aboud et al., 2021; Al-Ahbabi & Al-Jubouri, 2023).

The traditional method for extracting essential oils from lavender flowers is through distillation, where the flowers are exposed to boiling water or steam to release the oils. Distillation can take anywhere from a few minutes to several hours. The two main methods for extracting lavender essential oil are hydrodistillation and steam distillation (Wainer et al., 2022). The release of essential oil depends on the density of water at the ambient temperature (Filly et al., 2016). In their study, Filly et al. (2016) compared different extraction methods with the control sample of hydrodistillation to determine the yield and quality of the essential oil. In addition, they suggest using steam distillation assisted by microwave extraction to produce lavender oil in order to reduce the formation of by-products from chemical reactions. Wainer et al. (2022) conducted a study to determine the most suitable process for essential oil extraction, comparing steam distillation, hydrodistillation, and cellulase-assisted hydrodistillation. Before these methods can be used in production, they need to be evaluated at a small laboratory scale to determine their applicability (Filly et al., 2016).

The objective of this study is to compare the yields of lavender essential oil extracted using Clevinger hydrodistillation and steam distillation.

Materials and Methods

Experimental design

Field experience

The research was conducted in 2021 and 2022 after harvesting lavender plants from an experimental plot located in the Chirpan region, central Bulgaria (42°07′33″N 25°23′03″E, 147 m altitude). A four-year-old lavender plantation of the Sevtopolis variety was used. During the two investigated years, the plants were fertilized with an organic biostimulant called “Atlas Universal,” which was developed by a team of specialists from Trakia University, Bulgaria. The content of the organic biostimulant (mg/l) is: Macro and microelements: N – 61,593.3; P (P205) – 17,124.2; K (K_20) – 1245.4; Ca (CaO) – 128.2; Mg (MgO) – 25.7; S (SO_4) – 1669; Fe – 216; Mn – 6.90; Zn – 26; Cu – 6.62; Humic acids – 35.1%. The biostimulant was applied during the growing season, and the harvest took place at the beginning of July using a specialized harvester (Figure 1).

The experimental field was divided into five plots, as each plot has an area of 35 m^2. Each plot was fertilized differently as follows: Field I – 30 ml per plot; Field II – 50 ml per plot; Field III – 80 ml per plot; Field IV – 100 ml per plot. Additionally, one plot was left untreated as a control field. According to the recommendation of the manufacturers of the biostimulant, the indicated doses was applied twice during the growing season.

Extraction of the essential oil

Two methods are used to extract the essential oil from the lavender plants – steam distillation and hydrodistillation. The experiment was conducted in a laboratory, following the necessary technological requirements for the extraction processes. The purpose of using these methods is to determine the amount of essential oil extracted from each experimental plot of lavender plants. In a previous study by Hristova & Veleva (2022), the process of hydrodistillation was explained. The steam distillation process involves placing the plant material in water still and passing pressurized steam through it. The pressure of the steam causes the essential oils to be released and evaporate along with the steam. The vapor, containing the essential oil, then goes through a cooling system where it condenses into a liquid. The essential oil separates and floats on the surface of the water, making it easy to separate.

Statistical data analysis

The study compared the amounts of essential oil obtained from experimental fields treated with different doses of organic biostimulant using two methods – steam and hydrodistillation. The significant differences in the amounts of essential oil between the two methods for the years 2021 and 2022 were determined using Univariate ANOVA analysis with Post Hoc Games-Howell test. Correlation analysis was used to examine the relationship between the organic fertilizer used and the extracted amounts of essential oil.

Regression analysis was conducted to investigate the effect of organic biostimulant on the amount of essential oil obtained from each experimental field using steam and hydrodistillation. The analysis aimed to create predictive models with a significance level of $p < 0.05$. Two regression models – Linear (1) and Quadratic (2) – were compared using the following formulas:

$$Y = const.x + b \tag{1}$$

$$Y = const. + b_1x + b_2x^2 \tag{2}$$

The observed amount of essential oil obtained by steam and hydrodistillation is represented by Y. The factor amount of organic fertilizer is represented by x. The coefficients of the model are represented by const., b_1, and b_2. Computational procedures were conducted using the statistical package IBM SPSS Statistics 26.0.

Results and Discussion

The correlation analysis was used to calculate the strength of the relationship between the organic fertilizer used and the amounts of essential oil extracted through steam and hydrodistillation for the two years studied (2021 and 2022). The Univariate ANOVA analysis was used to determine significant differences in the amounts of essential oil obtained from the experimental fields treated with different doses of organic biostimulant.

Univariate ANOVA and Correlation analysis

The applied correlation analysis (Table 1) revealed a moderate correlation between the use of organic fertilizer and the amount of essential oil extracted by both studied methods – steam and hydro-distillation. Higher correlation coefficients (0.691; 0.491) were found between organic fertilizer and essential oil extracted through steam distillation for both years studied (2021 and 2022).

Table 2 presents the significant differences in the amounts of essential oil extracted, depending on the application of organic biostimulant in different experimental fields for each investigated method separately. The results indicate significant differences in the amounts of essential oil obtained through hydro-distillation between the control plot and Field I, and Field II in 2021. Additionally, significant differences

Fig. 1. Harvest of lavender plants in the study area

were observed between the amounts of essential oil extracted from Field I and Field III, Field IV, as well as between Field II and Field III, Field IV. The highest amount of essential oil (0.800 ml) in 2021 was obtained from Field I and Field II, treated with 30 ml and 50 ml of organic fertilizer per plot, respectively. In 2022, significant differences were observed between the amount of essential oil obtained from the control plot and all other experimental fields – Field I, Field II, as well as between Field II and Field III. The highest amount of essential oil (1.724 ml) in 2022 was extracted from Field II, treated with 50 ml of organic fertilizer.

Concerning the steam distillation, significant differences were observed in the amounts of essential oil extracted from the control plot and all other fields in the year 2021, as well as between Field I and the other fields. The highest amount of essential oil (1.677 ml) was extracted from Field I, which was treated with 30 ml of organic fertilizer. Similar results were obtained for the essential oil extracted by steam distillation in 2022. Once again, significant differences were found between the essential oil extracted from the control plot and all other fields except Field III, as well as between Field I and the other fields. The highest amount of essential oil (2.310 ml) was once again extracted from Field I.

The coefficients of determination R^2 for steam distillation in both years (0.918; 0.875) are higher compared to the coefficients obtained for Clevinger hydrodistillation (0.670; 0.900). Therefore, it is safe to conclude that the steam distillation method is the most suitable for extracting lavender essential oil when the field is treated with 30 ml of organic fertilizer per plot (Field I).

Figure 2 presents a comparison of the two methods (steam distillation and hydrodistillation) in terms of the amount of essential oil extracted from experimental fields treated with varying amounts of fertilizer. The figure shows that there were significant differences between the two methods in all test fields, except for Field III in 2022 ($R^2 = 0.020$; Sig. = 0.863). The highest coefficients of determination (0.977 and 0.944) for the two methods were calculated for Field I in the two years of study. Therefore, it can be concluded once again that 30 ml of organic fertilizer per plot is the most suitable option for fertilization.

Table 1. Crosstab correlation between the doses of organic fertilizer and the amount of essential oil extracted using the examined methods

Year			Amount of extracted essential oil, ml	
			Clevenger method	Steam distillation
2021 (n = 50)	Dose of the organic fertilizer, ml	Pearson Correlation	0.325*	0.691*
		Sig. (2-tailed)	0.021	0.008
2022 (n = 50)	Dose of the organic fertilizer, ml	Pearson Correlation	0.369*	0.491*
		Sig. (2-tailed)	0.000	0.000

*Correlation is significant at $p < 0.05$

Table 2. Univariate ANOVA of the observed parameter Amount of essential oil, ml extracted by the investigated methods from the fields fertilized with different doses of organic fertilizer

Variant (n = 50)	Clevenger method			Steam distillation		
	2021					
		Sig. (p)	R^2		Sig. (p)	R^2
Control	0.600 ± 0.103^{a}	0.001	0.670	0.987 ± 0.142^{a}	0.005	0.918
Field I	0.800 ± 0.082^{ab}			1.677 ± 0.059^{ab}		
Field II	0.800 ± 0.082^{ac}			1.208 ± 0.076^{abc}		
Field III	0.650 ± 0.082^{bcd}			1.126 ± 0.064^{abd}		
Field IV	0.500 ± 0.082^{bcd}			0.821 ± 0.089^{abcd}		
(n= 50)	2022					
Control	0.600 ± 0.103^{a}	0.001	0.900	1.420 ± 0.097^{a}	0.003	0.875
Field I	1.480 ± 0.144^{ab}			2.310 ± 0.047^{ab}		
Field II	1.724 ± 0.136^{abc}			1.970 ± 0.316^{abc}		
Field III	1.500 ± 0.183^{ac}			1.520 ± 0.312^{bcd}		
Field IV	1.600 ± 0.123^{a}			0.790 ± 0.058^{abcd}		

*Same superscripts within the same column represent significant differences at the level of significance $p < 0.05$ as follows: $^{a-a}$ between Control field and all other fields; $^{b-b}$ between Field I and all other fields; $^{c-c}$ between Field II and all other fields; $^{d-d}$ between Field III and all other fields; Post Hoc test: Games-Howell; SD – Standard deviation; R^2 – coefficient of determination; n – number of the observations.

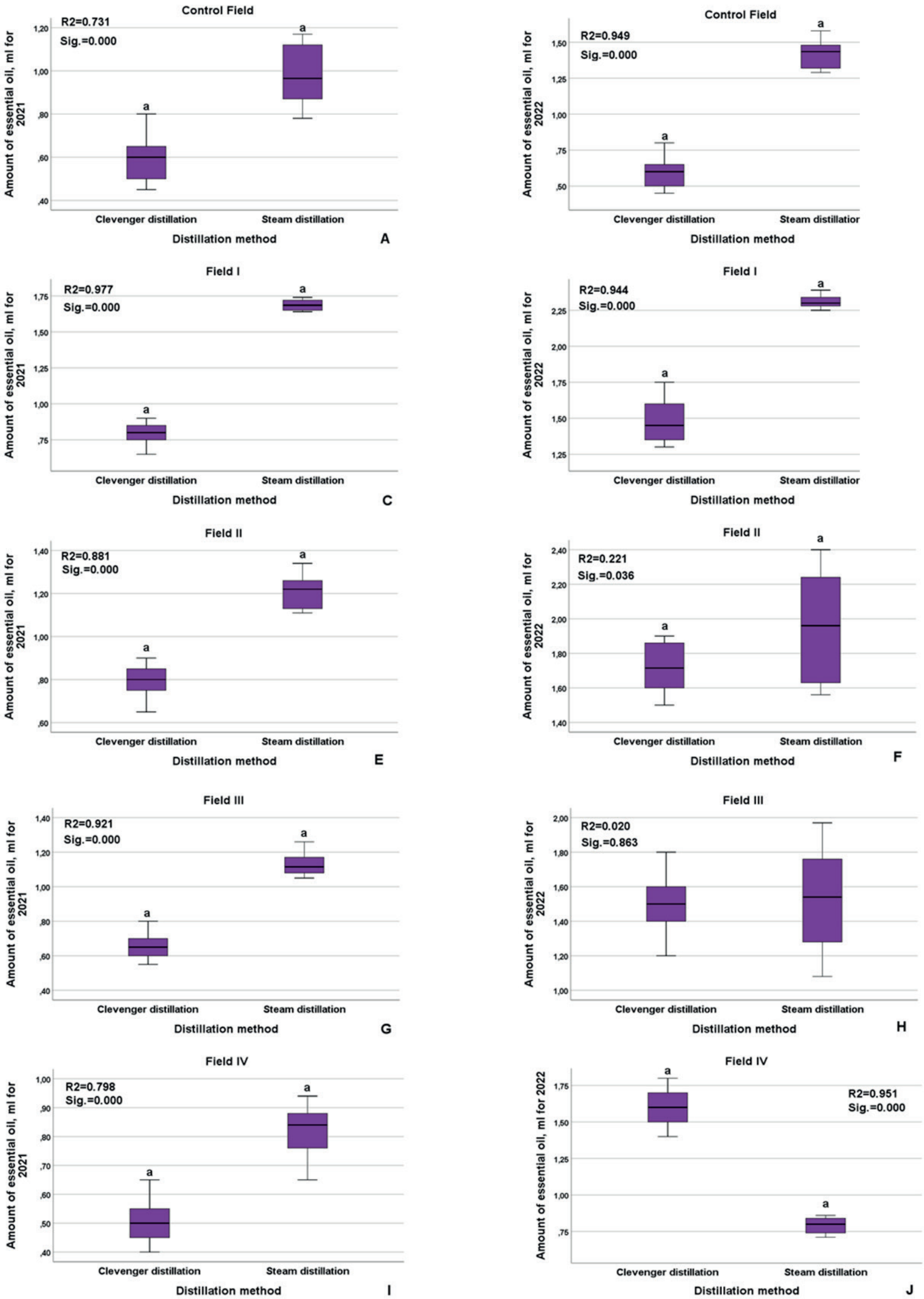

Fig. 2. Significant differences between both examined distillation methods based on the average amount of essential oil extracted from fields fertilized with different doses of organic fertilizer for 2021 and 2022

Regression models

The regression models calculated to show the relationship between the amount of organic fertilizer and the amount of essential oil obtained through steam and hydrodistillation for the two observed years are presented in Figure 3. The Quadratic model has higher coefficients of determination (0.627 and 0.660 for 2021, and 0.827 and 0.829 for 2022) compared to the Linear model (0.105 and 0.136 for 2021, and 0.477 and 0.241 for 2022). This indicates that the Quadratic model is more suitable for describing the influence of organic fertilizer on the extracted essential oil. Although the differences between the coefficients of determination for steam distillation and hydrodistillation are small, the coefficients for steam distillation are higher than those for hydrodistillation. This suggests that steam distillation is more suitable for extracting lavender essential oil.

The extraction of lavender oil from plants can be carried out using various methods, providing a basis for numerous researchers to conduct their studies. Danh et al. (2013) evaluated the effects of three different extraction methods, with the least amount of oil obtained through hydrodistillation. In another study, Liu et al. (2018) compared microwave-assisted hydrodistillation (MAHD) with conventional hydrodistillation (HD), and the results from ANOVA analysis indicated that MAHD could be a superior method for extracting essential oil from lavender and other aromatic plants. Additionally, Wainer et al. (2022) recommended hydrodistillation as the best method for commercial lavender oil production based on their investigation of three extraction methods. Furthermore, Liu et al. (2018) suggested steam distillation as the preferred approach for extracting lavender oil, as demonstrated in their experimental study.

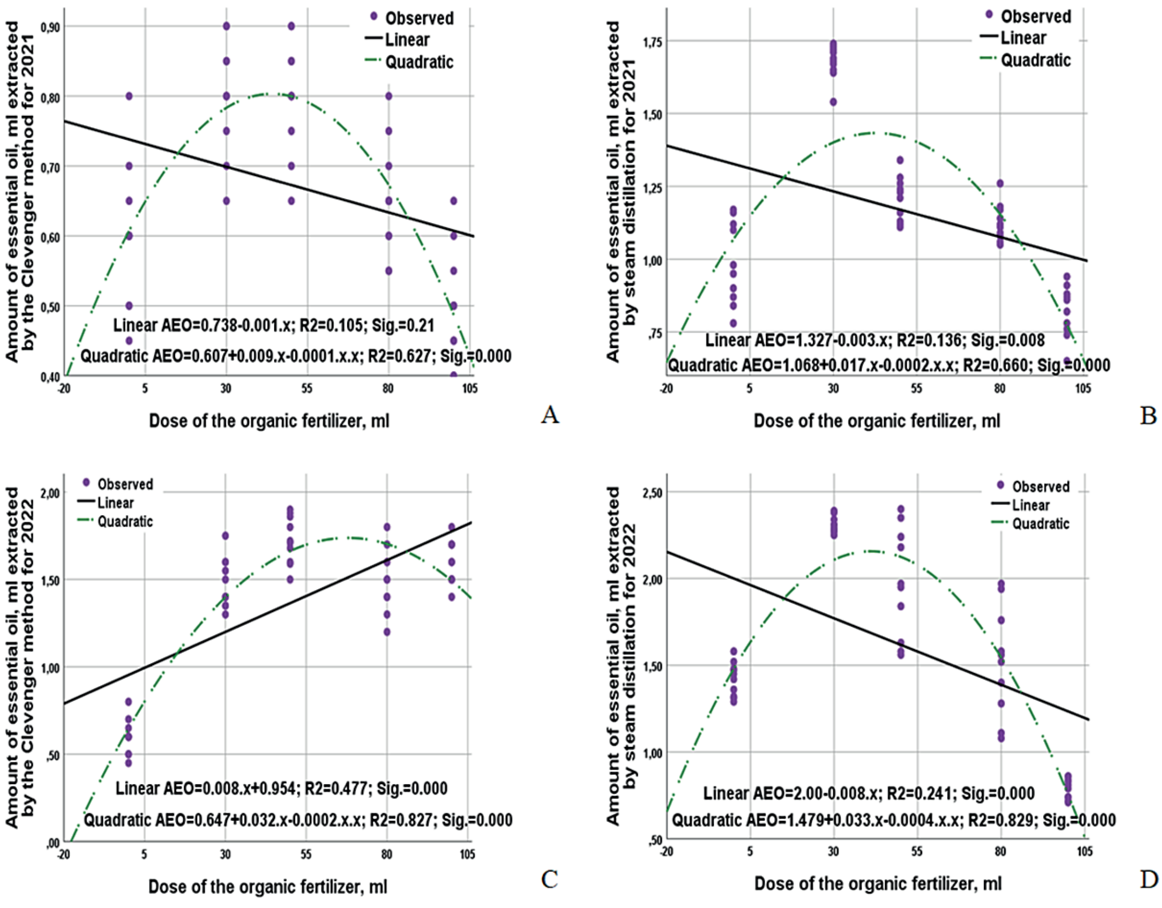

Fig. 3. Estimation of the regression models curves showing the relation between the amount of essential oil, extracted by the Clevenger method and Steam distillation for 2021 and 2022

Conclusions

The correlation analysis revealed higher correlation coefficients (0.691; 0.491) between the use of organic fertilizer and the extraction of essential oil through steam distillation for both years studied.

The highest amounts of essential oil (1.677 ml for 2021 and 2.310 ml for 2022) were extracted by the steam distillation method from Field I treated with 30 ml of organic fertilizer.

In the comparative analysis between Clevinger hydrodistillation and steam distillation, it was found that the highest coefficients of determination (0.977 and 0.944) for the two methods were calculated for Field I. This suggests that fertilization with 30 ml of organic fertilizer per plot is the most suitable option.

The coefficients of determination for the Quadratic model are higher than those for the Linear model in both investigated methods. This means that the Quadratic model better describes the effect of the amount of organic fertilizer on the amount of essential oil extracted. Specifically, the coefficients of determination are higher for the steam distillation method (0.660 and 0.829). Therefore, it can be concluded that steam distillation is more suitable for obtaining lavender essential oil.

Based on the given information, it is safe to conclude that the steam distillation method is the most suitable for extracting lavender essential oil when the field is treated with 30 ml of organic fertilizer per plot.

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