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INFLUENCE OF MINERAL FERTILIZERS AND PLANTING DENSITY ON THE GROWTH, DEVELOPMENT AND YIELD OF NARROW-LEAVED LAVENDER (*Lavandula angustifolia* Mill)

SUMMARY

The purpose of the research was to establish the influence of cultivation technologies on the productivity of narrow-leaved lavender. In a two-factor field experiment, the effects of three options for planting density (14.9 thousand plants/ha, 20.0 thousand plants/ha, 28.6 thousand plants/ha) and five options for the main application of mineral fertilizers ($N_{90}P_{90}K_{90}$, $N_{120}P_{120}K_{120}$, $N_{180}P_{180}K_{180}$ and $N_{240}P_{240}K_{240}$) on biometric dimensions, inflorescence yield, essential oil yield were studied. In a one-factor experiment, the influence of the foliar application of mineral fertilizers (N, P, K separately and NPK together) on the productivity of inflorescences and the content of essential oil was studied.

It was established that increasing the density of planting plants increased the productivity of narrow-leaved lavender. In the variants with the highest planting density - 28.6 thousand plants/ha, the yield of freshly picked inflorescences was from 5.51 to 9.48 t/ha, and the yield of essential oil was from 61 to 107 l/ha, depending on the dose of fertilizer application. A positive effect of the application of mineral fertilizers on lavender yield and essential oil yield was revealed. The highest yield of freshly picked inflorescences of 5.49-9.79 t/ha and the yield of essential oil 60-107 l/ha, depending on the density of planting, was obtained with the main application of mineral fertilizers in the dose of

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$N_{180}P_{180}K_{180}$. Foliar application of mineral fertilizers increased the productivity of lavender's inflorescences (N-by 8.1%, P-by 4.4%, K-by 4.4% compared to the control - without foliar treatments), but reduced the content of essential oil (N-by 4.6 ml/kg, P-by 4.5 ml/kg, K-by 2.9 ml/kg). Foliar application of complex fertilizer (NPK) increased the yield of lavender by 9.6%, reducing essential oil content by 2.7 ml/kg. The content of essential oil in dry inflorescences of narrow -leaved lavender among the investigated variants varied from 35.3 to 39.9 ml/kg.

Keywords: freshly picked inflorescences, yield of essential oil, content of essential oil, quality of raw materials

INTRODUCTION

Narrow-leaved lavender is a perennial semi-shrub of the Libosaceae family originating from the Mediterranean (Mihalascu *et al.*, 2020; Pokajewicz *et al.*, 2022; Svydenko *et al.*, 2022; Nedeltcheva-Antonova *et al.*, 2022). It is grown in Europe, Africa, the USA, and Australia. Flowers and essential oil of narrow-leaved lavender are medicinal raw materials. Demand for lavender essential oil is increasing worldwide (Tarakemeh *et al.*, 2012; Giray, 2018). The essential oil has sedative, carminative, antiseptic, anti-inflammatory, analgesic, and bactericidal properties. Narrow-leaved lavender is used by the pharmaceutical, cosmetic, perfumery, and food industries due to the wide range of actions of the essential oil (Pokajewicz *et al.*, 2022; Nedeltcheva-Antonova *et al.*, 2022).

For traditional cultivation zones, the yield and quality of the obtained raw material of narrow-leaved lavender primarily depend on the varietal characteristics and soil and climatic conditions of cultivation (Pokajewicz *et al.*, 2022; Crisan *et al.*, 2023). Its productivity is also significantly affected by cultivation technology, in particular the area of plant nutrition, provision of nutrients (Chrysargyris *et al*, 2016), moisture, and the level of agricultural technology (Crisan *et al.*, 2023).

Research conducted in 2017-2019 by romanian scientists (Mihalascu *et al.*, 2020), confirms that the main application of mineral and organic fertilizers increases the productivity of narrow-leaved lavender. Applying 40 t/ha of cattle manure will increase the yield of lavender's essential oil by 70% (Mavandi *et al.*, 2021). Iranian scientists found that the use of humic acids at a concentration of 5000 mg/l and vermicompost at a dose of 7.5 t/ha provided the highest yield of lavender flowers of 2522.17 kg/ha, with an essential oil content of 3.87% and an essential oil yield of 97.61 kg/ha (Sharafabad *et al.*, 2022).

Bulgarian scientists, who studied the effect of foliar application of microfertilizers on narrow-leaved lavender, found that fertilizers applied by the leaves in the budding phase significantly affect the yield of inflorescences and the yield of lavender essential oil. The average growth of inflorescences was from 25.2 to 29.4%, and the essential oil from 40 to 53.3% was higher than the control (Minev, 2020).

Scientists of the Cyprus University of Technology, who studied the effect of different concentrations of potassium on narrow-leaved lavender under hydroponic conditions, found that 300 mg/l is optimal for obtaining an increased content of essential oil in the raw material (Chrysargyris *et al*., 2017). A change in the concentration of phosphorus in the solution significantly affected the growth processes, and a decrease in the concentration of nitrogen below 150 mg/l reduced the content of chlorophyll. Essential oil yield remained unchanged at different levels of phosphorus and nitrogen concentrations (Chrysargyris *et al.*, 2016).

Narrow-leaved lavender is a drought-resistant plant, but in the initial stages, for intensive growth and development of plants, it needs high soil moisture and the provision of nutrients at an optimal level. This culture is usually grown in the Southern part of Ukraine, in particular, in the Crimea and the Kherson region (Svydenko *et al.*, 2022; Kremenchuk *et al.*, 2017). In the central part of the country, only introductory studies were conducted with narrow-leaved lavender until now.

However, given the climate change towards an increase in the average daily air temperature in the Forest-Steppe zone of Ukraine and the positive experience of the rapid northward expansion of closely related species of Mediterranean origin (Fedorchuk, 2008; Pryvedeniuk *et al*., 2019), the prospects for the success of research on the development of a technology for growing lavender under conditions of the central regions of Ukraine are quite obvious.

Therefore, since 2019, the Research Station of Medicinal Plants of the Institute of Agroecology and Environmental Management of NAAS has begun research on improving the elements of the technology for growing narrow-leaved lavender - *Lavandula angustifolia* Mill. to adapt this valuable crop to new soil and climatic conditions.

MATERIAL AND METHODS

The research was conducted in 2019-2022 on the lands of the Research Station of Medicinal Plants of the Institute of Agroecology and Environmental Management of the National Academy of Agrarian Sciences of Ukraine, which is located on the southern outskirts of the village of Berezotocha of the Lubensky District of the Poltava Region in the Eastern Left Bank part of the Forest-Steppe Zone of Ukraine at an altitude of 160 m above sea level, on the second terrace of the left bank of the Sula River. The location is determined by geographic coordinates: 50°50' north latitude and 30°11' east longitude.

The climate of the Forest-Steppe zone of Ukraine is of a transitional nature between the mild climate of Western Europe and the eastern continental climate. It is due to the increased solar radiation stress, the relatively southern location of the territory, as well as the peculiarities of the atmospheric circulation associated with the influence of the Mediterranean Sea and the Atlantic Ocean.

The weather conditions of the study area were as follows: the average annual air temperature was 9,7°C, the annual precipitation on average over the years of the study was 559.9 mm. The highest average monthly air temperature was 21.8°C in June, the lowest in January was -2.6°C. August was the driest, with an average of 16.5 mm of precipitation at an average monthly air temperature of 21.2°C. The highest amount of precipitation fell in May and December, but their amount was unevenly distributed over the years. May 2022 was the wettest, 176.3 mm of precipitation fell in the form of rain at an average monthly air temperature of 12.9°C. In general, the weather conditions of 2019-2022 were favorable for the growth and development of narrow-leaved lavender. (Table. 1).

Table 1. Meteorological conditions of 2019–2022 (The Research Station of Medicinal Plants, Berezotocha, Ukraine)

Climate factors	Years	Month												Average
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Average temperature (°C)	2019	-5.4	-0.6	3.8	10.4	17.3	23.4	19.9	20.4	15.6	10.5	4.1	2.0	**10.1**
	2020	0.2	1.3	6.6	8.9	12.9	22.1	21.2	20.7	17.9	12.4	3.3	1.6	**10.8**
	2021	-2.8	-5.6	1.8	7.6	14.7	20.6	24.2	21.6	13.1	7.6	4.2	-1.5	**8.8**
	2022	-2.3	0.6	1.4	8.5	14.3	20.9	20.0	22.2	12.2	9.7	2.8	-0.7	**9.1**
	Per years	**-2.6**	**-1.1**	**3.4**	**8.9**	**14.8**	**21.8**	**21.3**	**21.2**	**14.7**	**10.1**	**3.6**	**0.4**	**9.7**
														Total
Precipitations (mm)	2019	57.7	28.7	36.4	28.0	63.4	29.5	22.5	7.1	17.3	27.0	39.6	43.1	**400.3**
	2020	36.4	59.3	11.4	18.0	176.3	38.1	67.7	7.9	30.5	20.9	22.4	44.0	**532.9**
	2021	73.8	64.0	26.6	25.0	75.1	75.7	31.0	28.0	62.6	30.1	45.4	83.2	**620.5**
	2022	60.1	18.4	20.7	62.3	21.7	26.4	137.2	22.8	110.3	59.1	58.6	88.1	**685.7**
	Per years	**57.0**	**42.6**	**23.8**	**33.3**	**84.1**	**42.4**	**64.6**	**16.5**	**55.2**	**34.3**	**41.5**	**64.6**	**559.9**

The experimental scheme was planned according to the methods of B.O. Dospehova. considering the specifics of essential oil plants. The selection of plant samples, biometric measurements, and phenological observations were carried out according to the methods of A.I. Brikin. and Advice O.A. The repetition in the experiment is four times, the options' placement is random. The total area of experimental plots is 60 square meters, the area of accounting plots is 42 square meters.

The soil of the experimental field is heavy, low-humus, light loamy chernozem. The content of humus in the soil is average (2.43%), the thickness of the humus horizon is 80-90 cm, the content of easily hydrolyzed nitrogen is low (103.6 mg/kg of soil), the availability of mobile phosphorus is very high (384.4 mg/kg of soil), mobile compounds of potassium - increased (110.4 mg/kg of soil).

The predecessor was pure steam. Before laying out the experimental plot, plowing was carried out to a depth of 28-30 cm in the autumn period, moisture was closed with heavy harrows in the spring, and soil cultivation was carried out to a depth of 12-14 cm immediately before planting.

The experimental plot of narrow-leaved lavender was planted with 1-year-old seedlings in the third decade of March 2019. Narrow-leaved lavender seedlings were grown from seeds obtained from Spanish populations. Plants were planted with a row width of 1 m, this row width was chosen for the convenience of caring for plantations using small-sized equipment. In a row, plants were planted at 35 cm (14.9 thousand plants/ha), 50 cm (20.0 thousand plants/ha) and 67 cm (28.6 thousand plants/ha).

Before planting the plants, the main application of mineral fertilizer ($N_{16}P_{16}K_{16}$) was carried out in the dose of $N_{90}P_{90}K_{90}$, $N_{120}P_{120}K_{120}$, $N_{180}P_{180}K_{180}$, and $N_{240}P_{240}K_{240}$, the control was the option without fertilizer application. Foliar application of mineral fertilizers was carried out 3 times with an interval of 10 days, the last application was carried out in the phase of the beginning of flowering. Fertilizers used: for nitrogen application – urea (N_{34}), for phosphorus application – Yara Tera KRISTA MAP (P_{61}), for potassium application – Yara Tera KRISTA K PLUS (K_{46}) and for complex application of nitrogen, phosphorus, potassium – Yara Tera KRISTALON SPECIAL ($N_{18}P_{18}K_{18}$). In all variants, the concentration of the working solution was 2% with an application rate of 300 l/ha.

In the first year of cultivation, lavender was irrigated with a narrow-leaf drip irrigation system, and soil moisture in the 0-40 cm layer was maintained at 75-80% of the lowest moisture content. Soil moisture was monitored with tensiometric sensors of the SPG-II type.

Productivity was calculated during the flowering phase of the crop. Drying of freshly picked narrow-leaved lavender inflorescences was carried out by natural drying. The dryers used were equipped with good ventilation, and the air temperature during drying varied between 27-35°C. Inflorescences were spread with a layer of 4-6 cm on racks covered with fabric and the uniformity of the dehydration process was monitored. The drying period lasted 3-4 days. The collected raw materials were dried to a moisture content of 10-12%. In the first year of cultivation (2019), narrow-leaved lavender did not bloom harmoniously, the flowering period was very long, the number of inflorescences was insignificant, therefore it was not of economic value, and yield records were carried out starting from the second year of vegetation (the yield was calculated as the average for 2020-2022). Determination of the content of essential oil in the inflorescences of narrow-leaved lavender was carried out according to the method outlined in the State Pharmacopoeia of Ukraine using a Clevenger apparatus by distilling it with steam for 2 hours, followed by measuring the volume of essential oil in a graduated tube. The content of essential oil was determined in millilitres per kilogram of raw material in terms of absolutely dry raw material.

Statistical analysis of the results of experiment was performed by variance, correlation, and regression methods using the software Statistica, version 6.0 (TIBCO Software Inc.).

RESULTS

Studying the influence of planting density and mineral fertilizers on the biometric dimensions of narrow-leaved lavender, it was established that with an increase in the number of plants per unit area, their height increased, and the diameter of the bush decreased. So, in the version with a density of 14.9 thousand plants/ha, the height of the plants was from 51.6 to 61.4 cm, depending on the dose of fertilizer application, and the diameter of the bush was 74,5 to 91,4 cm. With an increase in the planting density to 20.000 plants/ha, the height of the plants increased slightly and was 52.5-63.9 cm, and the diameter of the bush decreased and was 72.2-90.9 cm. In the version with the highest planting density, the height of the plants was the greatest and was 53.0-65.1 cm, and the diameter of the bush was the smallest and was only 71.2-88.1 cm (Table 2).

It was found that an increase in the dose of the main application of mineral fertilizers contributed to an increase in the height of plants and the diameter of the bush, in the variants without the application of fertilizers, the height of the plants was 51.6-53.0 cm, the diameter of the bush was 71.2-74.5 cm. In the variants with the application of $N_{120}P_{120}K_{120}$ the height of the bush was 58.2-62.2 cm, and the diameter was 85.5-88.3 cm. The highest plant height of 61.4-65.1 cm with the largest diameter of the bush 88.1-91.4 cm was recorded in variants with the introduction of the highest dose of $N_{240}P_{240}K_{240}$ fertilizers.

The productivity of each individual narrow-leaved lavender plant was characterized by the weight of freshly picked inflorescences from one plant. During the calculations, a tendency to increase the weight of freshly picked inflorescences with a decrease in the density of planting plants was noted. In variants with a planting density of 28.6 thousand plants/ha, the weight of freshly picked inflorescences from one plant was the lowest and amounted to 193-332 g/plant. Reducing the density of lavender planting to 20,000 plants/ha slightly increased the weight of inflorescences and it was 203-343 g/plant. The highest weight of freshly picked inflorescences is 207-368 g/plant had plants in variants with the lowest planting density of 14.9 thousand plants/ha.

During the study of the effect of the main application of mineral fertilizers, a tendency to increase the productivity of narrow-leaved lavender plants with an increase in the dose of fertilizer application was revealed. In the variants with an application of fertilizer in a dose of $N_{60}P_{60}K_{60}$, the weight of freshly picked inflorescences from one plant was 217-253 g/plant. Increasing the dose of fertilizer application to $N_{120}P_{120}K_{120}$ increased the weight of inflorescences to 306-368 g/plant. The highest weight of freshly picked inflorescences is 332-368 g/plant had plants grown in variants with the application of fertilizers in the dose of $N_{180}P_{180}K_{180}$, further increase in the dose of fertilizers was ineffective. In variants without fertilization, the weight of freshly picked inflorescences was 193-207 g/plant.

Table 2. The effect of planting density and the main application of mineral fertilizers on the biometric parameters of narrow-leaved lavender (average for 2020-2022)

Variants		Height, cm	Diameter of bush, cm	Weight of freshly picked inflorescences of 1 plant, g
Factor A	Factor B			
14.9 thousand plants/ha (100x67 cm)	N_0 P_0 K_0	51.6 ±0.21a	74.5±0.14a	207 ±0,34 a
	N_{60} P_{60} K_{60}	53.8 ±0.04a	82.3 ±0.21b	253 ±0.42b
	N_{120} P_{120} K_{120}	58.2 ±0.01b	88,3 ±0.13b	329 ±1.15c
	N_{180} P_{180} K_{180}	60.3±0,11b	91.3 ±0.19c	368 ±0.89c
	N_{240} P_{240} K_{240}	61.4±0.11b	91,4 ±0.32c	351 ±1.34c
20.0 thousand plants/ha (100x50 cm)	N_0 P_0 K_0	52.5 ±0.04a	72.2 ±0.09a	203 ±1.02a
	N_{60} P_{60} K_{60}	56.9 ±0.12b	81.8±0.14b	230 ±0.76b
	N_{120} P_{120} K_{120}	61.5 ±0.05b	85.8 ±0.02b	324 ±1.25c
	N_{180} P_{180} K_{180}	63.1 ±0.25c	90.5 ±1.17c	343 ±1.09c
	N_{240} P_{240} K_{240}	63.9 ±0.07c	90,9 ±1.27c	331±2.19c
28.6 thousand plants/ha (100x35 cm)	N_0 P_0 K_0	53.0 ±0.02a	71.2 ±0.09a	193 ±0.34a
	N_{60} P_{60} K_{60}	57.5±0.09b	77.4 ±0.13a	217 ±0.49b
	N_{120} P_{120} K_{120}	62.2 ±0.12c	85.5 ±0.19b	306 ±0.97c
	N_{180} P_{180} K_{180}	64.4 ±0.03c	87.8 ±0.07b	332±0.78c
	N_{240} P_{240} K_{240}	65.1 ±0.01c	88.1 ±0.02b	326±1.57c
$LSD_{0,5\ \text{main effects f. A}}$		1.87	1.34	18.6
$LSD_{0,5\ \text{main effects f. B}}$		1.53	1.12	17.8
$LSD_{0,5\ \text{partial differences f. A}}$		2.27	2.01	20.1
$LSD_{0,5\ \text{partial differences f. B}}$		2.44	2.11	19.4

Note. The difference between the averages (for each parameter) under the different plants density and fertilizers application marked by not the same letter (a, b, c) are significant ($p < 0.05$); average value ± SD

The obtained results prove that with an increase in the density of planting narrow-leaved lavender, the productivity of inflorescences and the yield of essential oil per unit area increased. Thus, in the variants with the lowest planting density of 14.9 thousand plants/ha, the productivity of freshly picked inflorescences ranged from 3.08 t/ha to 5.49 t/ha, depending on the dose of fertilizer application. An increase in the planting density to 20.000 plants/ha contributed to a rise in freshly picked inflorescences yield to 4.12-6.85 t/ha. The highest yield of freshly picked narrow-leaved lavender inflorescences – 5.51-9.79 t/ha - was obtained in variants with the highest density of 28.6 thousand plants/ha. The dependence of the yield of dry inflorescences on the density of planting is similar to the yield of freshly picked inflorescences (Table 3).

Table 3. The influence of planting density and the main application of mineral fertilizers on the productivity of narrow-leaved lavender (average for 2020-2022)

Variants		Yield of freshly picked inflorescences, t/ha	Yield of essential oil, l/ha	Yield of dry inflorescences, t/ha
FactorA	Factor B			
14.9 thousand plants/ha (100x67 cm)	N_0 P_0 K_0	3.08 ±0.67a	34 ±1.12a	0.99 ±0.66a
	N_{60} P_{60} K_{60}	3.24±0.35a	36±0.03a	1.02 ±0.25a
	N_{120} P_{120} K_{120}	4.90 ±0.02a	54 ±0.87a	1.59 ±0.02a
	N_{180} P_{180} K_{180}	5.49 ±0.12b	60 ±2.78ab	1.75 ±0.29b
	N_{240} P_{240} K_{240}	5.23±0.27b	57 ±0.01a	1.69 ±0.34b
20.0 thousand plants/ha (100x50 cm)	N_0 P_0 K_0	4.12 ±0.89a	45 ±2.24a	1.31 ±0.05a
	N_{60} P_{60} K_{60}	4.59 ±0.11a	50 ±1.18a	1.48 ±0.01a
	N_{120} P_{120} K_{120}	6.72 ±0.22b	74 ±1.17b	2.16 ±0.17b
	N_{180} P_{180} K_{180}	6.85 ±0.04b	75 ±0.09b	2.26 ±0.02bc
	N_{240} P_{240} K_{240}	6.52 ±0.38b	71 ±2.34b	2.13 ±0.04b
28.6 thousand plants/ha (100x35 cm)	N_0 P_0 K_0	5.51 ±1.76b	61±0.47ab	1.75 ±0.17b
	N_{60} P_{60} K_{60}	7.24 ±1.62c	79 ±1.94b	2.29 ±1.56 c
	N_{120} P_{120} K_{120}	9.28 ±0.57c	102±2.35c	2.99 ±1.09c
	N_{180} P_{180} K_{180}	9.79 ±0.12c	107 ±0.58c	3.14 ±0.62c
	N_{240} P_{240} K_{240}	9.48 ±0.44c	104 ±2.02c	2.98 ±0.84c
$LSD_{0,5 \text{ main effects f. A}}$		0.89	4.65	0.14
$LSD_{0,5 \text{ main effects f. B}}$		0.72	4.48	0.11
$LSD_{0,5 \text{ partial differences f. A}}$		1.17	6.65	0.19
$LSD_{0,5 \text{ partial differences f. B}}$		1.06	6.32	0.16

Note. The difference between the averages (for each parameter) under the different plants density and fertilizers application marked by not the same letter (a, b, c) are significant ($p < 0.05$); average value ± SD

The yield of essential oil depended on the productivity of narrow-leaved lavender inflorescences, in variants with the lowest density of 14.9 thousand plants/ha of plants, it was the lowest and ranged from 34 to 60 l/ha. An increase in the planting density to 20.000 plants/ha contributed to an increase in the yield of essential oil up to 45-75 l/ha, depending on the dose of fertilizer application. The highest yield of essential oil of 61-107 l/ha was obtained in variants with the highest density of cultivation – 28.6 thousand plants/ha.

The effectiveness of the main application of mineral fertilizers for the cultivation of narrow-leaved lavender was quite high, as during the first year of vegetation, drip irrigation was used to eliminate the soil moisture deficit. Plants effectively used nutrients supplied with mineral fertilizers, as a result of which the intensity of their growth and development partially depended on the dose of fertilizer application. With an increase in the dose of the main application of fertilizers, the biometric dimensions of the plants and their productivity increased. So, in the options with the main application of fertilizer in the dose of $N_{60}P_{60}K_{60}$, the yield of freshly picked lavender flowers was from 3.24 to 7.24 t/ha, depending on the planting density. Increasing the fertilizer application rate to $N_{120}P_{120}K_{120}$ helped to increase the productivity of narrow-leaved lavender in variants with such a dose of fertilizer application, the yield of freshly picked inflorescences was 4.90-9.28 t/ha. The most effective fertilizer application dose was $N_{180}P_{180}K_{180}$, where the productivity ranged from 5.49 to 9.79 t/ha of raw materials, further increasing the fertilizer application dose was less effective. In variants without fertilization, the yield of freshly picked narrow-leaved lavender inflorescences was the lowest and ranged from 3.08 to 5.51 t/ha, depending on the planting density.

The use of mineral fertilizers helped to increase the productivity of narrow-leaved lavender and, at the same time, increased the yield of essential oil, so in the variants without applying fertilizers, the yield of essential oil was from 34 to 60 l/ha, depending on the density of planting plants. In variants with the application of fertilizers in the dose of $N_{60}P_{60}K_{60}$, the yield of essential oil was 36-79 l/ha. Increasing the dose of fertilizer application to $N_{120}P_{120}K_{120}$ contributed to an increase in the yield of essential oil to 54-102 l/ha. The highest yield of essential oil of 60-107 l/ha was obtained in variants with an application of fertilizers in the dose of $N_{180}P_{180}K_{180}$, further increase in the dose of application of fertilizers was less effective. During the study of the complex effect of planting density and the dose of mineral fertilizers on the productivity of narrow-leaved lavender, the lowest yield of freshly picked inflorescences of 3.08 t/ha with the lowest yield of essential oil of 34 l/ha was obtained in the variant with the lowest density of 14.9 thousand plants/ha without application of fertilizers The highest indicators of 9.79 t/ha of freshly picked inflorescences and 107 l/ha of essential oil were obtained at the highest density of 28.6 thousand plants/ha and with the introduction of mineral fertilizers in the dose of $N_{180}P_{180}K_{180.}$

The dependence of the yield of narrow-leaved lavender essential oil on the application of mineral fertilizers can be described mathematically by the following equations:

$$y = -2.9025x2 + 26.214x + 20.499, R^2 = 0.93,$$

where: y – yield of essential oil, l/ha,
x – dose of mineral fertilizers, kg/ha of active substance,
R^2 is the value of the reliability of the approximation.

The value of the reliability of the approximation is 0.93, which indicates the high reliability of the dependence of the essential oil of narrow-leaved lavender on the dose of mineral fertilizers (Figure 1).

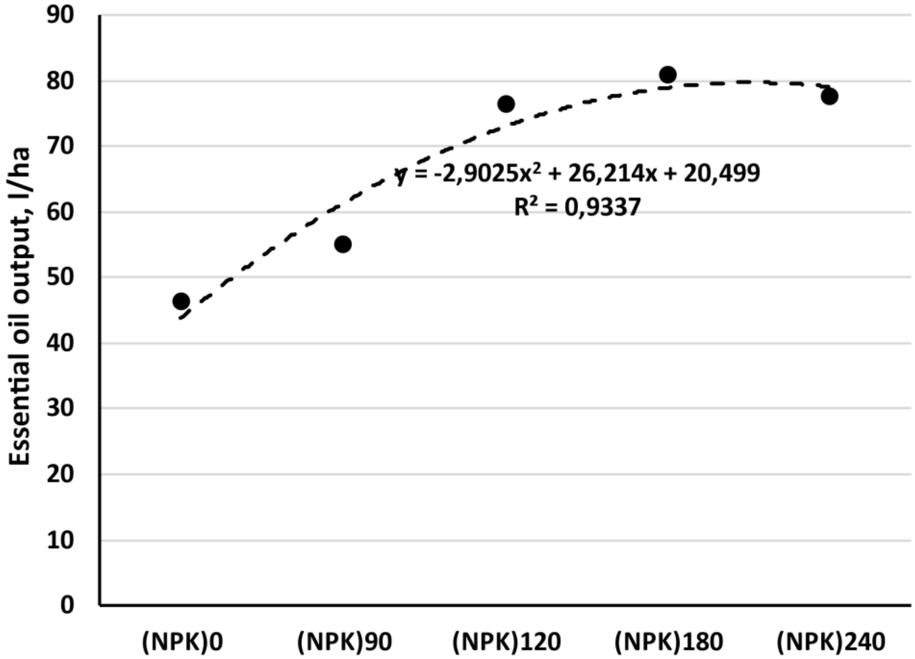

Figure 1. Dependence of the of narrow-leaved lavender essential oil output on the dose of mineral fertilizers

The main quality criterion of dry inflorescences of narrow-leaved lavender, which is used by the pharmaceutical industry for the manufacture of medicinal products, is the content of essential oil.

The influence of the foliar application of mineral fertilizers on the productivity and content of essential oil in the inflorescences of narrow-leaved lavender was studied. The obtained results indicate that three times foliar applications of nitrogen fertilizer increased the productivity of inflorescences by 8.1% compared to the control, but at the same time reduced the essential oil content by 4.6 ml/kg compared to the control.

The use of fertilizer with a high phosphorus content increased the yield of inflorescences by 4.4%, reducing the content of essential oil by 4.5 ml/kg compared to the control. Foliar application of potassium increased the yield of dry lavender flowers by 7,4%, reducing the content of essential oil by 2.9 ml/kg.

Foliar application of a complex mineral fertilizer increased the yield of lavender by 9.6%, and the raw material obtained in this variant contained 2.7 ml/kg less essential oil compared to the control. On the control variant, dry inflorescences of narrow-leaved lavender contained 39.9 ml/kg of essential oil (Figures 2, 3).

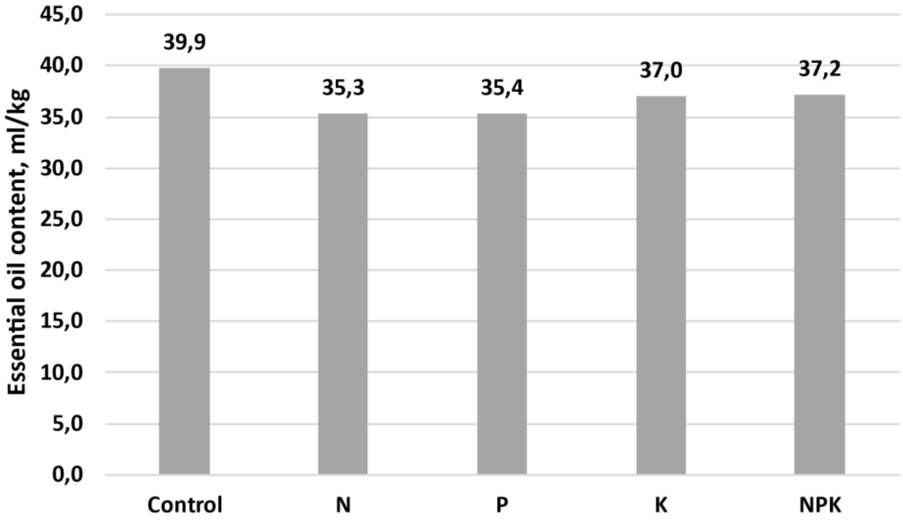

Figure 2. Effect of foliar application of mineral fertilizers on the essential oil' content in dry inflorescences of narrow-leaved lavender

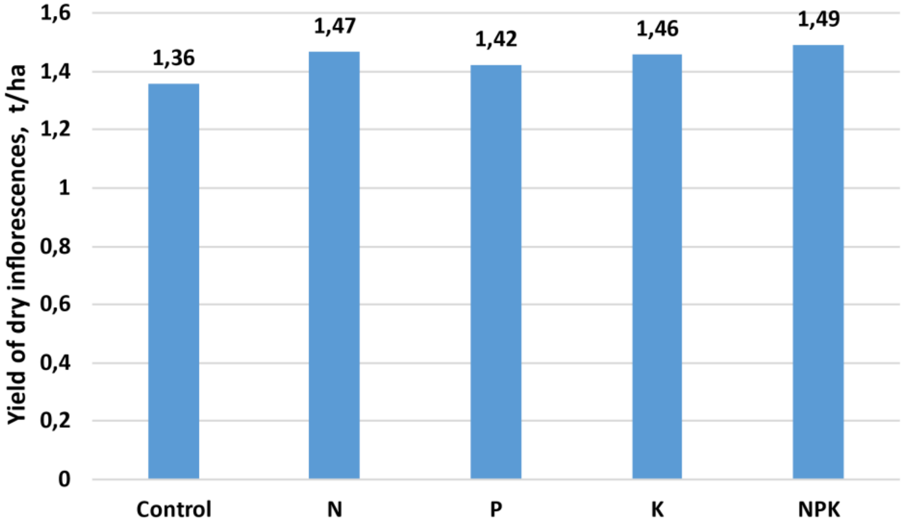

Figure 3. The effect of foliar application of mineral fertilizers on the dry inflorescences' productivity of narrow-leaved lavender.

Therefore, when the foliar application of mineral fertilizers, it is necessary to take into account the fact that with the increase in the yield of dry inflorescences of narrow-leaved lavender, the content of essential oil decreases somewhat.

According to the requirements of the European Pharmacopoeia and the State Pharmacopoeia of Ukraine, dry raw materials (inflorescences) of narrow-leaved lavender must contain at least 13 ml/kg, calculated on anhydrous raw materials. The obtained results indicate that in all studied variants of narrow-leaved lavender raw materials, the essential oil content indicators were 2.5-3.0 times higher relative to the minimum current requirements, which indicates the possibility of obtaining high-quality lavender raw materials in the production conditions of the Left Bank Forest Steppe of Ukraine.

DISCUSSION

Changes in weather conditions that have been observed in recent decades allow for revising the distribution zones of a number of essential oil crops, which until recently were considered suitable for cultivation only in the southern regions (Svydenko, *et al*., 2022). Among the crops that are rapidly expanding the area of cultivation, is the narrow-leaved lavender *Lavandula angustifolia* Mill. occupies a leading position (Svydenko *et al*., 2022; Kremenchuk *et al*., 2017; Rudnik-Ivashchenko *et al.,* 2018). Studies conducted in different soil and climatic conditions prove the prospects of this culture in the conditions of the Forest-Steppe zone of Ukraine (Kremenchuk *et al.,* 2017; Rudnik-Ivashchenko *et al.,* 2018). However, the highest productivity and product quality can be achieved by optimizing the growth and development of plants at the main stages of the formation of yield elements, which is convincingly proven by several studies on the study of medicinal and essential oil crops (Pryvedeniuk *et al*., 2021; Shatkovskyi *et al*., 2021). As research results show, at each stage of development, plants need specific ratios of environmental conditions, and the closer they are to the optimum, the better conditions are created for the formation of high plant productivity, especially for new growing areas (Pryvedeniuk *et al,* 2021).

The average annual rainfall during the growing season (April-October) of our research was 372 mm, which is sufficient for the intensive growth and development of narrow-leaved lavender. The obtained results indicate that increasing the density of planting lavender plants increased the productivity of inflorescences and the yield of essential oil in the first three years of harvesting. We obtained the lowest yield in the variants with a planting density of 14.9 thousand plants/ha, and the highest - in the variants with a planting density of 28.6 thousand plants/ha. A similar trend is observed with narrow-leaved lavender, an increase in planting density contributed to an increase in the yield of inflorescences, according to studies by Turkish scientists. Among the studied options, they obtained the highest yield of lavender flowers for the 30x30 cm cultivation scheme (111 thousand plants/ha) (Ceylan *et al,* 1996).

According to scientific sources, the use of fertilizers on narrow-leaved lavender has a positive effect on its growth, development and productivity (Chrysargyris *et al*., 2018; Crisan *et al*., 2023; Mavandi *et al.*, 2021; Sharafabad *et al.*, 2022; Elshorbagy *et al.*, 2020; Biesiada *et al.*, 2008). Providing lavender plants with nutrients due to the main application of fertilizers helps to increase the productivity of the crop. Studies by Brazilian scientists prove the high efficiency of organo-mineral fertilizers application to lavender increasing the dose of applying fertilizers increased the productivity of the culture (Silva *et al.*, 2017). Similar results were obtained by Egyptian scientists using mineral fertilizers, they got the highest productivity of lavender with the introduction of the largest amount of nitrogen, phosphorus, and potassium among the studied options (Ceylan *et al*., 1996). The results of our research confirm the high efficiency of using mineral fertilizers when growing narrow-leaved lavender. Increasing the dose of nitrogen, phosphorus, and potassium before planting lavender contributed to more intensive growth and development of plants. In variants with high doses of fertilization, plants had larger biometric sizes compared to the control and formed high yields of inflorescences and essential oil.

The obtained research results show that foliar application of nutrients increases the yield of lavender flowers, but at the same time slightly reduces the content of essential oil. This is explained by the fact that the mass of plants began to increase more intensively due to the introduction of an additional source of nutrients, but the accumulation of essential oil was not so rapid, there was an effect of reducing the concentration of essential oil due to the increase in biomass. Studies by Bulgarian scientists with foliar application of fertilizers indicate that they can increase and decrease the yield of lavender essential oil (Minev *et al.*, 2022). Therefore, when applying foliar fertilizers, you should strictly follow the recommendations, especially if fertilizers are applied before harvesting.

Based on the experience of domestic and foreign scientists, as well as on the results of own research with medicinal and essential oil crops, developing a system of agrotechnical measures for growing narrow-leaved lavender L*avandula angustifolia* Mill. in the conditions of the Left Bank Forest-Steppe of Ukraine, the peculiarities of the culture and new soil and climatic conditions for it were taken into account to create an optimal growing environment and obtain high productivity indicators.

CONCLUSIONS

According to the results of the research, the optimal level of mineral nutrition and planting density of narrow-leaved lavender plants were established. According to the yield criteria of inflorescences (9.79 t/ha) and essential oil (107 l/ha), the best option for mineral nutrition was the application of a dose of fertilizer $N_{180}P_{180}K_{180}$, and the best option for planting plants was a 100x35 cm scheme with a density of 28.6 thousand/ha.

The dependence of the yield of narrow-leaved lavender essential oil on the level of mineral nutrition of plants has been proven. The established dependence is described by a mathematical equation -y = -2.9025x2 + 26.214x + 20.499, and the approximation reliability value is 0.93, which indicates a high degree of reliability of the dependence of essential oil yield on the level of mineral nutrition.

The regularities of the influence of foliar top dressing with mineral fertilizers and complex fertilizers (NPK) on the yield of inflorescences and essential oil of *Lavender angustifolia* have been investigated and established. In particular, foliar top dressing with mineral fertilizers increased the yield of inflorescences (N-by 8.1%, P-by 4.4%, K-by 4.4% compared to the control - without foliar top dressing), but reduced the content of essential oil (N-by 4.6 ml/kg, P-by 4.5 ml/kg, K-by 2.9 ml/kg). Foliar application with complex fertilizer (NPK) increased the yield of inflorescences by 9.6%, reducing the content of essential oil by 2.7 ml/kg.

The generalized result of the research proved the possibility of forming a relatively high level of productivity of plantations of angustifolia lavender by optimizing mineral nutrition and planting density in the conditions of the Forest-Steppe zone of Ukraine.

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