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THE EFFECT OF MAIN MINERAL FERTILIZERS APPLICATION AND PLANTS NUTRITION AREA ON THE QUALITY OF THYME RAW PLANT MATERIALS (*THYMUS VULGARIS* L.) UNDER IRRIGATION CONDITIONS

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Досліджено вплив площі живлення рослин Thymus vulgaris L. на накопичення ефірної олії в сухій сировині (Thymiherba). Вивчалися чотири схеми вирощування: 45×40 см — 56 тис. росл./га, 45×30 см — 74 тис. росл./га, 45×20 см — 111 тис. росл./га. та 45×10 см — 222 тис. росл./га. Виявлено, що збільшення площі живлення рослин сприяло збільшенню вмісту ефірної олії в сухій сировині. Суха трава чебрецю звичайного з найбільшим вмістом ефірної олії 21,3 мл/кг була отримана у варіанті з найбільшою площею живлення рослин за схеми вирощування 45×40 см (56 тис. росл./га). Зменшення площі живлення дещо знижувало вміст ефірної олії. За схеми вирощування 45×30 см (74 тис. росл./га) її вміст знизився до 20,8 мл/кг, а за найменшої площі живлення рослин 45×10 см (222 тис. росл./га) вміст ефірної олії становив 18,5 мл/кг. Підтверджено, що основна маса ефірної олії у сировині чебрецю звичайного міститься у листі, квітах та дрібних пагонах, здерев'янілі стебла містять ефірну олію в слідових кількостях. За схеми вирощування 45×10 см (222 тис. росл./га) листя містили 34,2 мл/кг ефірної олії, стебла лише 2,1 мл/кг. Збільшення площі живлення рослин дещо підвищило якість сировини, за схеми вирощування 45×30 см (74 тис. росл./га) листя містило 35,9 мл/кг, стебла 2,1 мл/кг ефірної олії. За найбільшої площі живлення рослин при застосуванні схеми вирощування 45×40 см (56 тис. росл./га) вміст ефірної олії в листі був найвищим і становив 36,2 мл/кг Досліджено ефективність чотирьох норм основного внесення мінеральних добрив: $N_0P_0K_0$, $N_{60}P_{60}K_{60}$, $N_{120}P_{120}K_{120}$ та $N_{180}P_{180}K_{180}$. Встановлено, що збільшення норми внесення добрив сприяло збільшенню урожайності сухої сировини чебрецю звичайного та підвищувало вміст ефірної олії. Найбільш ефективною нормою внесення добрив є $N_{180}P_{180}K_{180}$, що забезпечило урожайність сухого листя на рівні 2,48 т/га із вмістом ефірної олії 38,2 мл/кг. Отримані результати свідчать, що зі збільшенням кількості висаджених рослин на одиницю площі частка листя в загальній масі сировини знижувалася з 52,3% до 45,1%, але за рахунок значного зростання продуктивності плантації урожайність сухого листя підвищувалася. Найвищу продуктивність плантації було зафіксовано у варіанті за схеми вирощування 45×10 см із щільністю висаджування рослин 222 тис. росл./га, де урожайність сухого листя чебрецю становила 1,52 т/га.

Ключові слова: *розсада, схема вирощування, ефірна олія, трава, листя, урожайність, краплинне зрошення.*

INTRODUCTION

Thyme (*Thymus vulgaris* L.) is a semi-shrub or perennial herbaceous plant originated from Mediterranean. Thyme is used in medicine and pharmacy as a valuable medicinal plant. Thymiherba is the aboveground part collected in the flowering phase is used as material for medicinal purposes. Its therapeutic effect is associated with a wide range of biologically active substances, including macro-and micronutrients and especially essential oil. Thymol and carvacrol are the most important substances in the essential oil con-

tent. Thyme herb also contains non-volatile phenolic compounds, mainly phenolic acids and flavonoids. Due to the wide range of biologically active compounds, thyme has such pharmacological properties as antispasmodic, antioxidant, antitussive and antimicrobial. Therefore, thyme and its products are used to treat diseases of the respiratory and digestive systems [1–3].

The food industry is a significant consumer of raw thyme. It is used as a natural preservative, cosmetics and perfumes component and as a spice in cooking. Its pleasant aroma, as well as high dietary and taste value make thyme one of the most popular spices, which is used both dry and fresh [4].

Thyme is introduced into the culture due to limited natural distribution and high demand. It is also cultivated in many countries around the world. Nowadays, there is a necessity to improve the cultivation techniques and the quality of raw materials due to thyme high economic importance and the rapid changes in climatic conditions.

Thyme belongs to the plants that have small seeds and needs special conditions for its germination. This greatly complicates reproduction due to direct sowing of seeds in open ground. Plantations of such crops are usually planted with seedlings with using of irrigation [5; 6]. It is necessary to create optimal conditions for the growth and development of thyme in order to increase the production of raw materials and improve its quality. Improvement of thyme growing scheme under drip irrigation is required due to the rapid changes in climate that. So an important issue is to determine the optimal nutrition area and establish effective doses of mineral fertilizers.

According to a number of studies, thyme is a sensitive crop to the use of mineral fertilizers, especially on irrigation. It is clear that not all fertilizers have the same effect on the quantity and quality of products according to scientific research and production experience. Thus, nitrogen fertilizers affect the yield of raw materials, but do not contribute to quality, in particular the content of essential oil. Phosphorus fertilizers, on the other hand, promote the formation of raw materials with a high content of essential oil, but do not have a significant impact on the growth of crop yields [7]. For German conditions, the optimal doses of fertilizers are 60–66 kg/ha of nitrogen, 30–50 kg/ha of phosphorus (P_2O_5) and 100–130 kg of potassium (K_2O) [8].

ANALYSIS OF RECENT RESEARCH

Lithuanian researchers studied the effect of nitrogen fertilizers on the yield and quality of raw thyme. They found out that nitrogen application increased the yield of dry grass and increased the yield of essential oil per unit area [9]. Scientists at the Czech Institute of Plant Breeding have studied the effect of foliar application of nitrogen, phosphorus, potassium and salicylic acid on the productivity of thyme. It was found that foliar fertilization increased the content of essential oil in comparison with the control by 18.76–42.47% [10]. An integrated approach to the cultivation of thyme is distinguished by the research of Iranian scientists. They studied the effectiveness of organic and mineral fertilizers and found out that organic fertilizers were more effective than mineral fertilizers for thyme cultivation. The introduction of phosphate-solubilizing bacteria, nitroxine and humus provided the highest yields of dry raw materials and the yield of essential oil [11]. Scientists from Tunisia, Saudi Arabia and the United States in cooperation have established thyme resistance to salinization of soils, which was enhanced by foliar application of potassium chloride and calcium chloride [12]. In Jordan, the effect of nutrition area on the productivity of thyme was studied. It was found that the highest yields of raw materials in both the first and second year of the growing season were obtained at a row spacing of 15 cm [13]. Iranian scientists have also studied the effect of the watering interval and nutrition area on the yield of thyme. It was found that with dense plantations of thyme, the weight of plants and the content of essential oil in the raw material decreased. Changing the intervals of irrigation periods did not affect crop yields [14].

A number of studies have shown that considering different climatic conditions the best cultivation of thyme is cultivation as a row crop for 2–4 years [15–17]. The best phases for harvesting raw materials are the phases recommended by regulations — the beginning and mass flowering of the culture. The ratio of crop volume and quality is optimal during this phase of development.

Small seeds and low competition of thyme seedlings cause another problem in growing of the crop. Weed infestation is a significant problem, especially in the early stages of crop growth and development. Comprehensive weed protection systems have been proposed in order to overcome this problem. Weed protection include the selection of the precursor, mechanical tillage and the usage of herbicides [18]. Weeding not only affects the condition of crops, but also significantly reduces the quality of raw materials [19]. Growing thyme using the seedling method of propagation greatly facilitates the protection of crops from weeds, especially in the first year of the growing season.

The expansion of the raw material base of thyme in Ukraine largely depends on the solution of the outlined problems. To increase the yield and improve the quality of raw thyme in the Left Bank Forest-Steppe of Ukraine, in the Research Station of Medicinal Plants IAE during 2018–2020 conducted research to improve the methods of seedling technology for growing under drip irrigation conditions.

The purpose of research is to establish the influence of the area of plant nutrition and the mineral fertilizers main application on the quality of raw thyme by the seedling method of reproduction under the conditions of drip irrigation.

MATERIALS AND METHODS OF RESEARCH

General methodological approaches typical for crop production research and special approaches used for medicinal plant growing were used it the study. In particular, the development of experimental schemes was carried out according to the methods of Dospekhov B.O. and Goryanskyi M.M. Sampling of plants, biometric measurements and phenological observations were carried out considering the peculiarities of medicinal culture according to Brykina A.I. and Porada O.A. methods [20–23].

Field experiments were carried out on the territory of the Research Station of Medicinal Plants IAE NAAS — the southern outskirts of Berezotocha village, Lubny district, Poltava region in the Eastern Left Bank of the Forest-Steppe zone of Ukraine at an altitude of 160 m above sea level, on the second terrace of the left bank. The location is determined by geographical coordinates: 50°50′ North latitude and 30°11′ East longitude.

The soils of the experimental field are powerful low-humus loamy chernozems. The humus content in the soil is medium (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 supply of mobile phosphorus is very high (384.4 mg/kg of soil), mobile potassium compounds are increased (110.4 mg/kg of soil) [24].

The thyme seedlings with a closed root system were used for laying research lots at the beginning of the experiment. Seedlings were grown in cassettes with a cell size of 40×40×60 mm. Sowing seeds in cassettes was carried out in the first decade of March, the seedlings were obtained for 7–9 days. Soil moisture during seedling cultivation was maintained at the level of 80–90% HB. Seedlings were planted in the open ground in the second decade of May according to the following schemes: 45×40 cm — 56 thousand plants/ha, 45×30 cm — 74 thousand plants/ha, 45×20 cm — 111 thousand plants/ha and 45×10 cm — 222 thousand plants/ha. During the growing season, the moisture content of the root layer of the soil was maintained at 80% of the lowest moisture content. The total size of the plots was 25–75 m^2, the accounting size is 20–30 m^2 with four repetitions.

Mineral fertilizers were applied to the main tillage at a dose of 60, 120 and 180 kg of the active substance nitrogen, phosphorus and potassium, the control was the option without any mineral fertilizers.

Determination of essential oil content was performed according to the method described in the State Pharmacopoeia of Ukraine [25].

RESULTS AND DISCUSSION

Restoration of active vegetation of thyme plants was observed for 3 days after planting seedlings in open ground. We did not observe differences between variants with different nutrition areas in the early stages of plant development. In the second half of the growing season there was a competition of plants for living space in variants with a high planting density of 111 and 222 thousand plants/ha.

It was found that the increase in the area of plant nutrition contributed to the increase in the content of essential oil in the dry raw material. The lighting of the plants was even and this had a positive impact on the development and functioning of the etheric glands. This also contributed to the essential oil accumulation in a raw material. Dry thyme grass with the highest content of essential oil — 21.3 ml/kg was obtained in the variant with the largest plant nutrition area of 45×40 cm (56 thousand plants/ha). Reducing the nutrition area slightly reduced the essential oil content. Thus, in the variant with planting scheme 45×30 cm (74 thousand plants/ha), essential oil content decreased to 20.8 ml/kg. In the variant with the smallest plants nutrition area of 45×10 cm (222 thousand plants/ha) the content of essential oil was at the level of 18.5 ml/kg (*Table 1*).

Threshing as a technological technique provides improvement of the raw materials quality. It implies separation and removing of woody stems. A mixture of leaves, flowers and small shoots (further simply — the leaves) has a much higher content of essential oil than grass, because the main part of the stems contain essential oil only in trace amounts.

According to the cultivation scheme 45×10 cm (222 thousand plants/ha), the leaves contained 34.2 ml/kg of essential oil, and the stem fraction contained only 2.1 ml/kg. Increase in the plant nutrition area to some extent improved the quality of raw materials, in the version of 45×30 cm (74 thousand plants/ha) leaves contained 35.9 ml/kg, stems — 2.1 ml/kg of essential oil. With the largest area of plant nutrition in the variant 45×40 cm (56 thousand plants/ha), the content of essential oil in the leaves was the highest — 36.2 ml/kg, the content of essential oil in the stems was the same as in previous schemes — 2.1 ml/kg.

According to the requirements of the State Pharmacopoeia of Ukraine (SPU), essential oil content in the raw material of thyme must be not less than 12 ml/kg for of anhydrous raw material. Dry thyme in all variants met the current requirements of SPU, even without threshing. In the variant with the largest nutrition area of 45×40 cm (56 thousand plants/ha), the dry thyme leaves had essential oil content that 3 times exceeded the requirements of SPU.

In medicinal plant growing, the efficiency of the developed elements of the technology of growing crops is assessed by the gross collection of raw materials and seeds, as well as the yield of biologically active substances. Together with yield of raw materials accounting the calculation of the yield of essential oil per unit area was also performed in order to

Table 1. **The effect of plants nutrition area on essential oil content in thyme raw plant material**

Variants	Essential oil content in dry raw plant material, ml/kg			Yield of dry grass, t/ha	Estimated yield of essential oil, l/ha
	grass	leaves	steams		
45×40 cm (56 thousandplants/ha)	21.3	36.2	2.9	1.70	36.2
45×30 cm (74 thousandplants/ha)	20.8	35.9	2.3	2.46	51.2
45×20 cm (111 thousandplants/ha)	20.1	34.4	1.9	3.05	61.3
45×10 cm (222 thousandplants/ha)	18.5	34.2	2.1	3.37	62.3
$HIP_{0,5}$	0.2	0.2	0.1	0.27	2.4

determine the effectiveness of drip irrigation for thyme cultivation. The calculation was based on the yield of particular variant and the content of biologically active substances (essential oil) in the raw material per 1 hectare. It was found that the estimated essential oil yield in dry raw materials for cultivation schemes 45×10 cm (222 thousand plants/ha) was the highest – 62.3 l/ha due to the highest total yield of raw material. Reducing the number of plants per unit area reduced the yield of raw materials and respectively the yield of essential oil. Thus, in the variant of the cultivation scheme 45×20 cm (111 thousand plants/ha), the estimated yield of essential oil was 61.3 l/ha, and in the variant 45×40 cm (56 thousand plants/ha) – 36.2 l/ha and was minimal for researched variants.

The mineral fertilizers application has one of the most important impacts for the effective application of drip irrigation. It was found that the main mineral fertilizers application had a positive effect on the content of essential oil in dry grass. Increasing the dose of fertilizers increased the content of essential oil in the dry raw material. In the control variant (without fertilizer application) the content of essential oil in dry grass was only 19.9 ml/kg, when the main mineral fertilizer application was at dose $N_{60}P_{60}K_{60}$ the essential oil content increased to 21.1 ml/kg. The highest essential oil content was 22.4 ml/kg in dry raw material. It was obtained in the variant with the main mineral fertilizer application at a maximum researched dose of $N_{180}P_{180}K_{180}$ (*Table 2*).

Dry thyme leaves with the mineral fertilizers main application at a dose of $N_{60}P_{60}K_{60}$ contained 35.4 ml/kg of essential oil, increase the mineral fertilizers dose to $N_{120}P_{120}K_{120}$ contributed to increase in the of essential oil content up to 36.3 ml/kg. The highest quality of dry leaves in terms of essential oil content – 38.2 ml/kg was obtained in the variant with the main fertilizer maximum dose – $N_{180}P_{180}K_{180}$. In the control variant without fertilizer, the content of essential oil in the leaves was 34.9 ml/kg.

The estimated yield of essential oil from 1 hectare depended on both the content of essential oil in the raw material and the yield of dry raw material. In the control variant it was the lowest – 62.8 l/ha. Mineral fertilizer main application at a dose of $N_{60}P_{60}K_{60}$ increased the essential oil yield to 77.4 l/ha. The highest estimated yield of essential oil – 105.1 l/ha was obtained with application of the highest dose of mineral fertilizer $N_{180}P_{180}K_{180}$.

The pharmaceutical industry of Ukraine uses the above-ground part of thyme – dry grass (*Thymiherba*) for the production of medicines. However, dry thyme leaves become more popular for that purpose. According to the requirements of the European Pharmacopoeia, the raw material of thyme is dry leaves with flowers separated from the stems. Therefore, during the research, the influence of plant nutrition area and mineral fertilizers on dry leaves yield was established (*Figs. 1, 2*).

It was found out that with the increase in the number of plants per unit area, the share of leaves in the total weight of grass decreased from 52.3% to 45.1% [26]. However, with a significant increase in the overall productivity of densely planted plantations, the yield of dry leaves increased. Thus, in the variant

Table 2. **The effect of mineral fertilizers on the essential oil content in thyme raw plant material**

Variants	Essential oil content in dry raw plants material, ml/kg			Dry grass yield, t/ha	Estimated yield of essential oil, l/ha
	grass	leaves	steams		
$N_0P_0K_0$ (control)	19.7	34.9	2.1	3.19	62.8
$N_{60}P_{60}K_{60}$	21.1	35.4	1.9	3.67	77.4
$N_{120}P_{120}K_{120}$	21.9	36.3	2.2	4.22	92.4
$N_{180}P_{180}K_{180}$	22.4	38.2	2.1	4.69	105.1
$HIP_{0,5}$	0.2	0.3	0.1	0.34	3.1

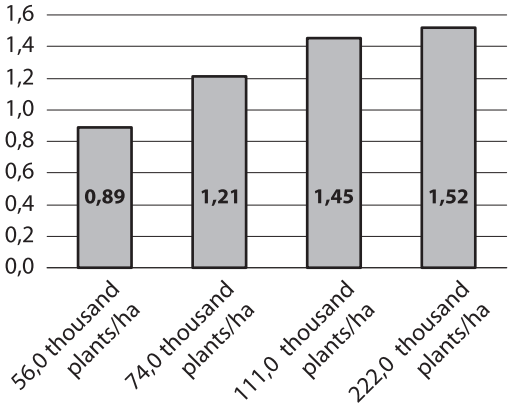

Fig. 1. The effect of planting density on the yield of dry thyme leaves

of the cultivation scheme 45×40 cm with a planting density of 56.0 thousand plants/ha, the yield of dry leaves was 0.89 t/ha. Increasing the number of plants to 74 thousand plants/ha contributed to increasing the yield of leaves to 1.21 t/ha. The highest productivity of the plantation was recorded in the variant with a planting density of 222 thousand plants/ha, where the yield of dried thyme leaves was 1.52 t/ha.

The mineral fertilizers main application increased the share of dried thyme leaves by 6.5%. In the variant with the application of $N_{60}P_{60}K_{60}$, the yield of dry leaves was 1.76 t/ha, increasing the dose of fertilizer to $N_{120}P_{120}K_{120}$ provided dry leaves yield increase to 2.18 t/ha. At the highest dose $N_{180}P_{180}K_{180}$, the yield was 2.48 t/ha exceeding the control by 1 t/ha. The use of drip irrigation provided a fairly high efficiency of the mineral fertilizer main application. The use of irrigation during the growing season

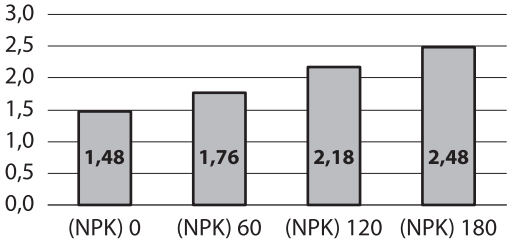

Fig. 2. The effect of the mineral fertilizers main application on thyme dry leaves yield

provided the moisture content of the root layer of the soil at the level of 80% HB and had a positive effect on the absorption of nutrients by plants.

Reducing the number of plants per 1 hectare by increasing the plant nutrition area increases the content of essential oil in dry raw materials, but significantly reduces crop yields, which should be taken into account when forming plantations. Based on the obtained experimental data, the recommended scheme of the seedling method of growing thyme in the conditions of production can be 45×20 cm with a planting density of 111 thousand plants/ha. The recommended doses of the main application of mineral fertilizers in the seedling cultivation of thyme can range from $N_{120}P_{120}K_{120}$ to $N_{180}P_{180}K_{180}$.

CONCLUSIONS

The results of the experiments proved that the increase in the plant nutrition area of thyme plants contributed to the essential oil content incensement in the dry raw material. The highest essential oil content in the dry raw thyme was obtained in the variant 45×40 cm (56 thousand plants/ha), where the area of plant nutrition was maximum.

The dependence between the essential oil content in dry grass incensement and mineral fertilizers dose increase was revealed during the research. The best conditions for the essential oil accumulation in the raw material were in the variant with the mineral fertilizer main application at a dose of $N_{180}P_{180}K_{180}$.

It was also found out that with the increase in the plants per unit area, the share of leaves in the total mass of raw materials decreased by 7.2%. However, due to a significant increase in plantation productivity, dry leaves yields increased. The highest yield of dry thyme leaves — 1.52 t/ha was recorded in the variant of cultivation schemes 45×10 cm with a planting density of 222 thousand plants/ha.

The use of drip irrigation provided a fairly high efficiency for the mineral fertilizers main application. In the variant with the application of $N_{180}P_{180}K_{180}$ the yield of dry thyme leaves was the highest — 2.48 t/ha exceeding the control variant by 1 t/ha.

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