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# EFFECT OF ENVIRONMENTAL CONDITIONS ON YIELD AND QUALITY OF NARROW-LEAVED LAVENDER (*Lavandula angustifolia* MILL)

## WPŁYW WARUNKÓW ATMOSFERYCZNYCH NA PLON I JAKOŚĆ LAWENDY WĄSKOLISTNEJ (*Lavandula angustifolia* MILL)

**Abstract:** The objective of this study was to determine the effect of soil and weather conditions during three vegetation seasons (2001, 2003 and 2004) on the yield of the narrow-leaved lavender herb as well as on the content and composition of volatile oils in the flowers of this plant. Field experiments were conducted on three 4-year old plantations of lavender in the 3rd year of cultivation. The site of this study was Krepa near Golcza, located in Miechow Upland. The yields of both the fresh and dry matter of inflorescences and flowers (spikes) of lavender were affected by: weather conditions during the vegetation seasons, size of plants, number of flowering branches and number of flower rings in spikes. At the same time, the weather and soil conditions had no effect on the total content of volatile oils in flowers of lavender. However, the relative content of major terpenes ie linalool, linalyl acetate, geraniol and borneol in lavender oil was altered

**Keywords:** narrow-leaved lavender, vegetation season, yield of inflorescences, number of flowering branches, volatile oils, luvisol, loess

Narrow-leaved lavender is an evergreen perennial shrub growing originally at high altitudes in the Mediterranean region (eg France, Italy, Spain, North Africa). Large-scale commercial cultivation of lavender was first started in France, Italy and Spain in the 17th century. It was later developed in Bulgaria, Croatia, Hungary and Poland in the 20th century [1].

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The environmental needs of lavender are relatively high. The plant grows well on soils rich in nutrients and with pH ranging from neutral to alkaline. It resists dry periods thanks to a well developed root system. On the other hand it is sensitive to large amplitude of day and night temperatures, especially in the beginning of vegetation in spring [2–6].

This paper analyses the responses of lavender plants, grown in Miechow Upland, to varying soil and weather conditions during three vegetation seasons (2001, 2003 and 2004). The first aim was to determine yield of lavender herb (inflorescences and flowers). Second, to determine the content and composition of volatile oils in flowers of the plants.

## Material and methods

The site of this study was Krepa near Golcza (50°19′16.8″E 19°56′45.7″N, 360 m a.s.l), located in Miechow Upland. The soil is classified as a Haplic Luvisol [7], derived from loess and consists of 13 % sand, 75 % silt and 12 % clay. The humus horizon this soil characterized by pH 6.5–6.5, C/N ratio – 8.1 and high-level water field capacity (Table 1). Soil samples were taken twice a year in spring (before it was fertilized) and in autumn (after harvest) from two horizons; A – 0–15 cm and B – 15–30 cm. The following soil analyses were carried out: organic carbon content; total nitrogen by the Kjeldahl method [8]; total porosity [9], water field capacity as a soil water potential −15.5 kPa; pH in 1M KCl (1/2.5 v/v); plant-available phosphorous P and K by the Egner–Riehm method, and plant-available Mg by the Schachtschabel method [8]. The basic conditions of the soil are shown in Table 1.

Soil field experiments were conducted on three 4-year old plantations of lavender in the 3rd year of cultivation. The forecrop for each lavender plantation in the first year of cultivation (1998, 2000 and 2001) was wheat grown on manure (30 Mg/ha).

At present there are no registered Polish cultivars of lavender. Therefore, lavender grown on plantations in the Gołcza region was of local origin. Lavender seedlings were produced from locally available seeds and planted in the three permanent sites. Consequently, the lavender plants in the studied plantations were of different origin and varied in shape and size.

Two experimental factors were studied: the vegetation season (years 2001, 2003 and 2004) and the size of lavender plants (S – small plants with the diameter of 45–64 cm; M – medium plants with the diameter of 65–84 cm; L – large plants with the diameter of 85–115 cm). Each year, eighteen plants (6S, 6M and 6L) from each plantation were evaluated to determine: (1) fresh matter of inflorescences (g/plant), (2) number of flowering branches per plant, (3) number of flower rings in spikes, (4) number of flowers in a flower ring, (5) dry matter of inflorescences (g/plant) and (6) dry matter of flowers (g/plant). Lavender inflorescences were collected manually (with a sicle) on the following harvest dates: 15 July 2001, 8 July 2003 and 3 July 2004. These biometrical data were subjected to two-factorial analysis of variance.

Samples of dried lavender flowers were steam-distilled in a steam distillation Deryng apparatus [10] to extract volatile oils, and their content was expressed in g/100 g of the

dry material. The extract was further analyzed for individual volatile oils on a gas chromatograph (Pye Unicam) equipped with a capillary column (Supelco). This analytical data were subjected to one-factorial analysis of variance.

## Results and discussion

This soil represents typical Haplic Luvisol derived from loess at the Miechow Upland. Soils in this region are characterized by silty texture with a very good physical condition to cultivate plants, especially physical conditions like bulk density and water field capacity (Table 1). The studied soil had a very good water capacity like most of the silty soils from loess. We observed the highest yield of lavender in 2001. Exactly in this year precipitation was the highest throughout the whole experiment and the soil absorbed most of this rainfall and next could supply pants with water for the longer time than in 2003 and 2004. Presumably it was the most important factor that influenced the yield of lavender throughout the experiment.

Table 1

Selected properties of the soil

| Horizon symbol | Depth [cm] | pH in KCl | % of particle size of the fine soil fraction [μm] | | | Organic C [g · kg$^{-1}$] | Bulk density [Mg · m$^{-3}$] | Total porosity [m$^3$ · m$^{-3}$] | Field capacity moisture [m$^3$ · m$^{-3}$] |
|---|---|---|---|---|---|---|---|---|---|
| | | | 2000–63 | 63–2 | < 2 | | | | |
| A | 0–30 | 6.52 | 13 | 75 | 12 | 17.1 | 1.44 | 0.44 | 0.35 |
| E1 | 30–40 | 6.18 | 13 | 74 | 13 | 4.4 | 1.47 | 0.44 | 0.33 |
| E2 | 40–65 | 6.19 | 13 | 76 | 11 | 2.3 | 1.36 | 0.49 | 0.36 |
| E2/Bt | 65–104 | 6.18 | 12 | 79 | 9 | 2.6 | 1.43 | 0.45 | 0.37 |
| Bt | 104–135 | 4.67 | 11 | 63 | 16 | 1.3 | 1.52 | 0.41 | 0.37 |
| C | 135–160 | 4.32 | 8 | 76 | 16 | 1.4 | 1.72 | 0.34 | 0.33 |

The humus horizon of the analyzed soil was rich in organic carbon. That is one of the reasons for a high content of plant available P, K and Mg. In most soils the upper horizon of 0–15 cm had a higher content of plant available P, K and Mg (Table 2). A tendency towards an increased content of organic carbon was observed (Table 2). These soils were characterized by very stable pH and small standard deviations throughout the whole experiment (Table 2). An insignificant decrease of plant available P, K and Mg was observed in 2003 and 2004 comparing to 2001, especially in Mg (Table 2). The changes of analyzed soil conditions were not significant, but small tendency increasing and decreasing were observed. It means that soil conditions were similar in each year of this experiment and a lavender had not influence of on soil conditions. It means that weather condition together with correct fertilizer had the most important influence on yield of the lavender.

Table 2

Changes in soil pH, organic carbon, and plant- available potassium, phosphorus and magnesium during years experiment (average concentration, ± standard deviation).
A – horizon 0–15 cm, B – horizon 15–30 cm

| Date | pH in KCl | | Organic C | | $K_2O$ | | $P_2O_5$ | | MgO | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | [g · kg$^{-1}$] | | [mg · kg$^{-1}$] | | | | | |
| | A | B | A | B | A | B | A | B | A | B |
| 2001 spring | 6.9 ± 0.3 | 7.0 ± 0.1 | 7.7 ± 0.4 | 7.3 ± 0.9 | 200.8 ± 12.0 | 192.8 ± 13.3 | 259.2 ± 38.9 | 230.7 ± 13.0 | 151.8 ± 19.8 | 150.9 ± 31.0 |
| 2001 autumn | 6.8 ± 0.1 | 6.9 ± 0.1 | 7.8 ± 0.6 | 7.0 ± 1.0 | 170.0 ± 20.5 | 183.3 ± 40.3 | 222.7 ± 31.9 | 214.0 ± 48.1 | 136.5 ± 17.3 | 122.5 ± 18.1 |
| 2003 spring | 6.7 ± 0.1 | 6.9 ± 0.1 | 8.6 ± 1.0 | 8.7 ± 0.5 | 194.4 ± 40.6 | 146.0 ± 14.3 | 252.6 ± 34.9 | 198.1 ± 24.2 | 67.0 ± 7.2 | 82.7 ± 17.4 |
| 2003 autumn | 6.9 ± 0.1 | 6.8 ± 0.2 | 8.5 ± 0.4 | 7.2 ± 0.4 | 178.5 ± 20.2 | 130.3 ± 23.0 | 219.4 ± 21.1 | 190.6 ± 38.1 | 114.9 ± 21.2 | 99.1 ± 15.2 |
| 2004 spring | 6.8 ± 0.1 | 6.9 ± 0.1 | 9.0 ± 1.5 | 8.7 ± 0.8 | 194.4 ± 40.6 | 146.0 ± 14.3 | 247.4 ± 23.2 | 178.2 ± 14.1 | 92.9 ± 24.7 | 88.9 ± 4.7 |
| 2004 autumn | 6.8 ± 0.1 | 6.8 ± 0.1 | 9.0 ± 0.8 | 8.5 ± 1.5 | 178.5 ± 20.2 | 130.3 ±23.0 | 242.4 ± 30.4 | 183.1 ± 20.2 | 99.1 ± 14.8 | 92.3 ± 14.6 |

The results obtained in this study confirmed the effect of weather conditions (Fig. 1, 2) in three vegetation seasons (2001, 2003 and 2004), on both the yield and the quality of the lavender herb.

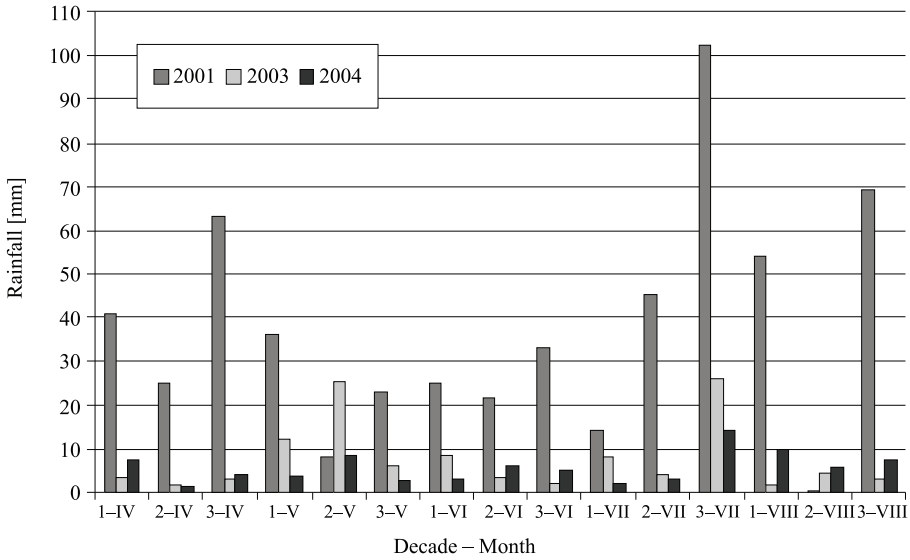


Fig. 1. Amount of rainfall per decade in analyzed seasons

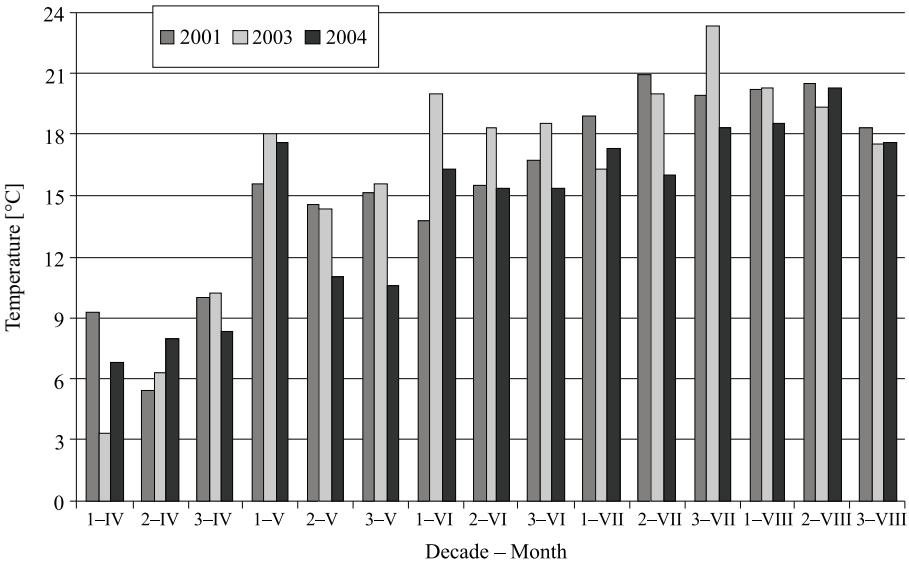


Fig. 2. Average air temperature per decade in analyzed vegetation seasons

Table 3

Inflorescence yield (fresh matter) of lavender [g/plant] depending on vegetation season and plant size

| Years | Plant size | | | Means for years | LSD for years |
|---|---|---|---|---|---|
| | S | M | L | | |
| 2001 | 469 | 728 | 1090 | 762 | 93.07 |
| 2003 | 147 | 314 | 508 | 323 | |
| 2004 | 132 | 399 | 727 | 419 | |
| Means for plant size | 249 | 480 | 775 | | |
| LSD for plant size | 93.07 | | | | |

Table 4

Dry matter lavender inflorescence [g] yield depending on vegetation season and plant size

| Years | Plant size | | | Means for years | LSD for years |
|---|---|---|---|---|---|
| | S | M | L | | |
| 2001 | 127 | 219 | 281 | 209 | 29.7 |
| 2003 | 41.3 | 87.0 | 149 | 92.6 | |
| 2004 | 32.7 | 108 | 219 | 119 | |
| Means for plant size | 67.2 | 138 | 216 | | |
| LSD for plant size | 29.7 | | | | |

Table 5

Dry matter lavender flowers [g] yield depending on vegetation season and plant size

| Years | Plant size | | | Means for years | LSD for years |
|---|---|---|---|---|---|
| | S | M | L | | |
| 2001 | 52.8 | 74.0 | 109.0 | 78.8 | 10.6 |
| 2003 | 17.0 | 35.5 | 58.8 | 37.1 | |
| 2004 | 12.3 | 39.5 | 77.8 | 43.2 | |
| Means for plant size | 27.4 | 49.7 | 82.1 | | |
| LSD for plant size | 10.6 | | | | |

Table 6

Number of inflorescences developed on lavender plants [piece] depending on vegetation season and size of plants

| Years | Plant size | | | Means for years | LSD for years |
|---|---|---|---|---|---|
| | S | M | L | | |
| 2001 | 632 | 1041 | 1444 | 1039 | 136.7 |
| 2003 | 196 | 416 | 642 | 418 | |
| 2004 | 167 | 548 | 1007 | 574 | |
| Means for plant size | 332 | 668 | 1031 | | |
| LSD for plant size | 136.7 | | | | |

The highest yields of the fresh and dry matter of inflorescences (Table 3 and 4), dry matter of flowers (Table 5), and also, the highest numbers of flowering branches (Table 6), and flower rings in inflorescences (Table 7), were recorded in the first year of the study ie 2001.

On the other hand, the lowest and the highest numbers of flowers in rings were recorded in 2001 and 2004, respectively (Table 8). The first vegetation season (April–August 2001) was warm and its average monthly temperatures were close to long-term temperatures for this site, although they were lower than those recorded during the seasons of 2003 and 2004 (Fig. 1 and 2). In addition, intensive rainfall (> 60 mm) which doubled the long-term average and were recorded in the 3rd decade of April could increase the number of flowering branches and thus yields. In 2001 inflorescences were harvested in mid July. The flowering phase was equilibrated and the yield of fresh matter of inflorescences was 5.8 Mg/ha.

Table 7

Number of flower rings developed on lavender inflorescences [piece] depending on vegetation season and plant size

| Years | Plant size | | | Means for years | LSD for years |
|---|---|---|---|---|---|
| | S | M | L | | |
| 2001 | 6.7 | 6.3 | 6.7 | 6.6 | 0.7 |
| 2003 | 5.2 | 5.7 | 6.3 | 5.7 | |
| 2004 | 5.5 | 5.3 | 6.0 | 5.6 | |
| Means for plant size | 5.8 | 5.8 | 6.3 | | |
| LSD for plant size | 0.7 | | | | |

Table 8

Number of lavender flowers developed in a flower ring [g] depending on vegetation season and plant size

| Years | Plant size | | | Means for years | LSD for years |
|---|---|---|---|---|---|
| | S | M | L | | |
| 2001 | 8.20 | 9.00 | 7.80 | 8.30 | 2.10 |
| 2003 | 10.3 | 10.7 | 9.50 | 10.2 | |
| 2004 | 11.3 | 10.7 | 11.8 | 11.3 | |
| Means for plant size | 10.1 | 9.7 | 8.2 | | |
| LSD for plant size | 2.1 | | | | |

In contrast, different environmental conditions were noted in 2003. Plant vegetation was delayed and snowless winter resulted in frost damages of lavender plants. The plants produced flowering branches from root crowns and not from tops, thus resulting in lower number of the branches and lower yields of fresh and dry matter of inflorescences (Table 3, 4, and 6). Temperatures recorded in the first and the second decade of April was below the long time average (2 °C). On the other hand, a significant increases

of temperature was recorded in May (the first and the third decade), reaching 16.5 °C and exceeding the long-time average by 23 %.

The amount of rainfall in April was 34.3 mm, amounting to 69 % of the long-time average, whereas in May the rainfall was largely scattered. The first and the second decade of June were warm, with the average temperature of 13 % higher than in May and reaching 19.1 °C. In contrast, the amount of monthly rainfall was only 38 % of the long-term average. In spite of warm and dry June, flowering branches of lavender plants were of different length, flowering was extended in time, underdeveloped flower rings dried early and finally all this affected yield of plants. The plants were harvested in the 1st decade of July yielding 2.04 Mg/ha of inflorescences. In the first decade of May 2004, temperatures were stable and warm. However, in the next two decades a 5 °C decrease in temperature was recorded. In June and July, air temperatures were similar. In 2004 (June–August), total rainfall was 234 and 39 mm higher than in 2001 and 2003, respectively. The plants were harvested in the beginning of July and the yield of inflorescences was 3.3 Mg/ha.

Available data on the yields of narrow-leaved lavender plants recorded in Poland are scarce and imprecise. According to Ruminska [2], the yield of lavender flowers in the second year of cultivation is low and amounts to 100 kg/ha. In next years it increases to 300–500 kg and 600–1000 kg of thredshed and unthreshed flowers, respectively. Also Nowak [3] indicates that the yield of lavender flowers amounts to 1000–1200 kg/ha. In our experiment the yield of dry threshed flowers varied from 615 kg/ha in 2003 to 1295 kg/ha in 2001, and was similar to the results reported earlier.

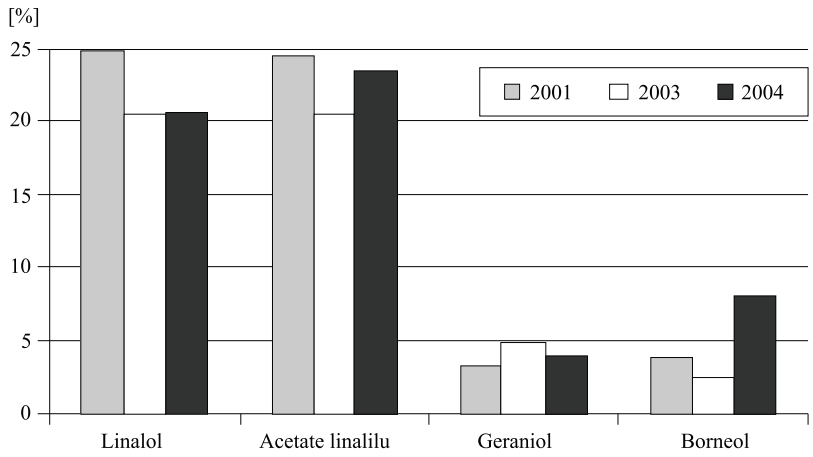


Fig. 3. Content of terpens in lavender flowers in analyzed vegetation seasons

The weather conditions during vegetation seasons (2001, 2003 and 2004) had no effect on the total volatile oil content in lavender plants. However, relative proportions of individual volatile oil were affected. The average content of volatile oils in lavender flowers was 2.39 % and varied from 2.53 to 2.58 % in the third year of cultivation. Ac-

cording to Ruminska [11], the volatile oil contents is affected by a number of factors, eg a plant origin, a season, an extraction method and may vary from 0.7 to 3 %. Similarly, the oils contents reported by Turowska and Stepien [1] and Cybulska et al [12] was 1.33–1.73 and at least 1.7 %, respectively. In contrast, Czikow and Łaptiew [13] obtained the range of 4–5 %. Therefore, it can be concluded that the volatile oils content in lavender, in our experimental conditions, was on a fairly high level. The individual volatile oils in lavender oil determined in our analyses were: linalool, linalyl acetate, geraniol and borneol. Among three vegetation seasons, the highest levels of linalool and linalyl acetate were recorded in 2001, as resulting from suitable weather conditions (Fig. 3). In 2003, the contents of linalool and linalyl acetate were slightly lower than in 2001, and in 2004, the level of lianool remained the same as in 2003 but the level of lianalyl acetale rose. The content of geraniol in lavender oil in the three analyzed vegetation seasons was the highest in 2003, and of borneol in 2004.

In Poland, lavender is mainly cultivated for its inflorescences (bunches) or flowers (potpourri or lavender oil). In the case of lavender oil use in cosmetology, the high level of lianalyl acetale is especially important [14, 15], because of its characteristic scent, as well as lianool. In the conducted experiments, the content of both terpenes has been high and similar to the top level in lavender oil [16].

## Conclusions

1. The analyzed soil was characterized by very good conditions to cultivate narrow-leaved lavender. An insignificant decrease of plant available P, K and Mg was observed in 2003 and 2004 as compared with 2001.

2. The effect of weather conditions during three vegetation seasons (2001, 2003 and 2004), was significant and influenced the amount of fresh and dry matter of inflorescences yield, flowers and the number of flowering branches and flower rings developed on the narrow-leaved lavender plants. The highest yield was obtained in 2001, during the vegetation season with high total rainfall (578 mm) and the optimum average (April–May).

3. Two components of the harvest structure had a significant influence on the yield of lavender inflorescences and flowers, namely, the number of flowering branches developed on plants and the number of flower rings. In the analyzed years 2001, 2002 and 2004, the plants developed 1039, 418 and 574 flowering branches on the plants, respectively, and 6.6, 5.7 and 5.6 flower rings in spikes.

4. Among three vegetation seasons the weather conditions were different, which did not influence the content of the oil significantly but the percentage of every terpen. The highest contents of lianool and lianalyl acetale were recorded in the vegetation season of the year 2001.

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## WPŁYW WARUNKÓW ATMOSFERYCZNYCH NA PLON I JAKOŚĆ LAWENDY WĄSKOLISTNEJ (*Lavandula angustifolia* MILL)

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**Abstrakt:** Badano wpływ warunków glebowych oraz przebiegu pogody w trzech sezonach wegetacyjnych (2001, 2003 i 2004) na plony lawendy wąskolistnej, a także zawartość i skład olejków eterycznych w kwiatach tego gatunku. Badania polowe prowadzono na trzech, czteroletnich plantacjach lawendy, w trzecim roku użytkowania roślin. Plantacje doświadczalne położone były w miejscowości Krępa, koło Gołczy na Wyżynie Miechowskiej. Plony zarówno świeżych, jak i suchych kwiatostanów i kwiatów lawendy były uzależnione od przebiegu pogody w badanych sezonach wegetacyjnych, wielkości roślin, liczby wykształconych kwiatostanów oraz liczby nibyokółków. Natomiast warunki pogodowe i glebowe nie miały wpływu na zawartość olejku w kwiatach lawendy wąskolistnej. Jakkolwiek widoczna była zależność udziału głównych terpenów, takich jak linalolu, octanu linalolu, geraniolu i borneolu w olejku lawendowym w poszczególnych latach badań.

**Słowa kluczowe:** lawenda wąskolistna, sezon wegetacyjny, olejki eteryczne, gleba płowa, less