Acta Sci. Pol. Hortorum Cultus, 21(2) 2022, 19–34

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 https://doi.org/10.24326/asphc.2022.2.2

ORIGINAL PAPER

Accepted: 27.08.2021

# EFFECTS OF LIGHTLESS TILLAGE, FLAME WEEDING AND GLUFOSINATE-AMMONIUM ON WEED SUPPRESSION IN SUMMER SAVORY (*Satureja hortensis* L.)

Andrzej Borowy, Magdalena Kapłan

Institute of Horticultral Production, Department of Pomology, Nursery and Enology, University of Life Sciences, Głęboka 28, 20-612 Lublin, Poland

## ABSTRACT

The objective of this three-year study was to investigate the usefulness of flame weeding, spraying with glufosinate-ammonium and nighttime soil tillage for weed suppression in summer savory. The experiment was arranged in a split-plot design with three experimental factors and four replications. The soil was cultivated with a rotary tiller a day before savory sowing or an hour after sunset on the night preceding sowing, while flaming (90 kg propane·ha$^{-1}$) and glufosinate-ammonium (600 g·ha$^{-1}$) were applied, depending on the year, 12–22 days after sowing, i.e. after the emergence of weeds and the first savory seedlings. Flaming and glufosinate-ammonium killed all weeds growing during the treatment but they did not prevent new weeds from emerging on the following days. Three weeks later, the number of weeds growing on plots weeded with the flame method and sprayed with glufosinate-ammonium was significantly lower by about 63 and 69% in comparison to control, respectively, and it was independent of the time of soil tillage. The studied methods had no effect on weed infestation assessed 3–4 weeks after the first weeding, or on the emergence, plant height and yield of fresh savory herb. The content of oil in dry herb varied from about 1.9% to 2.4% depending on the year while it did not depend on the weeding method. Oil produced by control plants contained 35 compounds making up 99.85% of the total, with the predominant share of carvacrol (45.2–46.8%) and γ-terpinene (34.6–39.9%). Much smaller was the share of α-terpinene (4.8%), p-cymene (2.7–4.0%), myrcene (1.5–2.0%) and α-thujene (1.4–1.8%). The average share of the remaining components did not exceed 1%.

**Key words:** weed flora, savory emergence, plant height, herb yield, essential oil content and composition

## INTRODUCTION

Summer savory (*Satureja hortensis* L.) is an annual plant from the Lamiaceae family native to the Mediterranean Basin and Near East [Mordalski 2018]. Savory plant develops a strongly branched stem, reaching the height of up to 60 cm and lignified at the base [Senderski 2009]. The plant was known and used in human medicine already in ancient times, and also today it arouses great interest due to many valuable properties [Hamidpour et al. 2014]. In Poland, it has been grown since 9$^{th}$ century [Rumińska 1983] and currently it belongs to the most important herbal and spice plants in the country [Newerli-Guz 2016]. According to Rumińska [1991], the average yield of summer savory fresh herb is 40 kg·100 m$^{-2}$, but in favorable conditions it may be higher. Yields harvested in several experiments conducted in Poland were very diverse, depending on seed sowing or transplants planting and harvesting time, plant nutrition, as well as

✉ magdalena.kaplan@up.lublin.pl

the method of cultivation, the number of harvests and plant habitat. They ranged from 34 to 356 kg·100 $m^{-2}$ [Czabajska et al. 1994, Martyniak-Przybyszewska and Majkowska-Gadomska 2006, Kucharski and Mordalski 2007, Zawiślak 2008, Seidler-Łożykowska et al. 2009, Dzida et al. 2015, Skubij and Dzida 2019]. Summer savory is cultivated from direct sowing into the field and its emergence does not start until about 3 weeks after sowing [Senderski 2009, Dzida et al. 2015, Mordalski 2018], which makes it very susceptible to competition of earlier germinating weeds. According to Rumińska [1991], this is the time of the greatest sensitivity of savory to weed competition. Research conducted so far on the protection of savory crops against weeds is very scarce. In a two-year experiment of Kucharski and Mordalski [2007], a lack of weed control or mechanical weeding of interrows alone led to a complete loss of yield. Research conducted in Germany by Pank [1992] showed that manual labor inputs for weeding 1 ha of savory crop amounted to 330 hours, which constituted 95% of the total weeding effort, and that an efficient use of herbicides allowed for a reduction of these inputs by almost 90%. Kucharski and Mordalski [2007] demonstrated the usefulness of linuron applied immediately after sowing summer savory in controlling mainly dicotyledonous weed species [Praczyk and Skrzypczak 2004], while Kordana et al. [2002] showed the usefulness of fluazifop-P-butyl applied post-emergence for controlling barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) and couch grass (*Elymus repens* (L.) Gould) in this crop. Pank [1992] found no negative influence of several tested herbicides on the share of leaves in summer savory plant weight, nor on the dry matter and oil content in its dry herb. However, in an experiment of Kucharski and Mordalski [2007], the influence of linuron on the content of essential oil in the raw material of summer savory was varied and unclear.

In the cultivation of herbal plants with a long emergence period, such as savory, it would be very beneficial to kill weeds by means of total herbicides, e.g. glufosinate-ammonium [Kordana et al. 1997, Borowy and Kapłan 2022] or flaming [Carrubba and Militello 2013] just before crop emergence. Such a treatment would provide good growth conditions for slowly growing savory seedlings, which after the emergence mark the rows of plants, and thus facilitate the use of mechanical weeding tools. Glufosinate-ammonium is a nonselective foliar herbicide of limited movement in the xylem or phloem [Senseman 2007], inhibiting the effect of glutamine synthetase [HRAC 2020] and exposing low toxicity to humans [Praczyk and Skrzypczak 2004]. It is rapidly degraded by microbes in soil or surface water [Senseman 2007]. Kordana et al. [1997] and Borowy and Kapłan [2022] obtained good results using it at a dose of 600 g·$ha^{-1}$ just before lemon balm emergence, but so far there has been no such information referring to summer savory.

Flame weeding has been known for several decades and now it is gaining attention due to the increasing restrictions on the use of herbicides [Knežević 2016], especially in the cultivation of herbs used in human and animal therapy [Carrubba and Militello 2013]. It proved to be useful in the protection of several annual and perennial herbal plant species against weed infestation [Borowy and Kapłan 2022], but so far there is no such information regarding savory. This method consists in destroying young weeds with high temperature generated in a burner in the process of propane-butane gas combustion [Ascard 1995]. The amount of gas burnt depends on several factors, especially the species and growth phase of the weed, and usually it ranges from 40 to 60 kg·$ha^{-1}$. However, it can sometimes be as high as 80-150 kg·$ha^{-1}$ [Ascard 1995, Knezevic et al. 2009, 2014, 2014a]. A relatively high cost of gas makes this method more expensive than the chemical one, but cheaper than manual weeding [Nemming 1994]. Moreover, flame weeding as a thermal process is allowed in organic farming [Council Reg. 2007], where it is seen as one of the most promising alternatives for weed control [Knezevic 2017]. Flaming can be also used after the emergence of some crops, e.g. corn, sorghum, soybean and sunflower, when conducted properly at the most tolerant stage growth [Knezevic 2017]. The response of many other crops to this treatment needs to be determined [Knežević 2016].

Another non-chemical method of weed suppression is the practical use of the photo-induction (photoblasticism) phenomenon, which involves lightless tillage. Its effectiveness is conditioned by many factors, including temperature and rainfall, type of soil, method of farming, application of fertilizer as well as the dormancy and quiescence state of weed seeds

[Dobrzański 2011, Hartmann 2016]. In 3 experiments conducted by Ascard [1994], harrowing at night or in daylight with a light-protected harrow decreased the emergence of weeds significantly by 40, 63 and 14%. The number of lamb's quarters (*Chenopodium album* L.) showed a non-significant reduction of 22% and the number of common chickweed (*Stellaria media* (L.) Vill.) was reduced significantly by 77%. In an indoor experiment of Andersson et al. [1997], a vast majority of 41 annual and one perennial studied weed species germinated to higher percentages after a 5-s light exposure than in constant darkness. However, in many of the species, seeds from different populations differed significantly in their response to light. According to the authors, large differences in germination percentage and the light response between populations imply that weed seed germination after soil cultivation in darkness will be difficult to predict. In four-years studies conducted by Gallagher and Cardina [1998], the light environment during disking generally had a slightly greater effect on emergence than during plowing. Emergence of redroot pigweed (*Amaranthus retrofexus* L.), smooth pigweed (*Amaranthus hybridus* L.) and giant foxtail (*Setaria faberi* Herrm.) was, at most, 30 to 55% higher following day vs. night disking. Emergence of other weeds was not affected by the light environment during tillage. The authors concluded that night tillage may not be a viable approach to weed management due to insufficient reductions in weed emergence associated with night tillage and the high degree of variability in the recruitment response to light conditions during tillage. Gerhards et al. [1998] observed that in 11 out of 12 field experiments photocontrol of weeds resulted in about 20 to 80% less emergence of annual weed seedlings, with different responses of individual weed species to the day- or nighttime tillage. In one experiment, weed seedling emergence was not influenced by light when the soil was extremely dry during tillage. Based on the results of the authors' own research as well as the numerous literature data, Juroszek et al. [2017] suggested that night-time soil tillage may delay the process of desiccation of the upper soil layer, thereby favoring the emergence of early emerging small seeded weeds. According to Dobrzański [2011], lightless tillage, with its high variability and often low effectiveness in controlling weeds, can complement other more effective methods.

In Poland, in a two-year experiment carried out by Adamiak [2004], the number of weeds growing on plots cultivated at night was lower by 9–19% in comparison to daylight cultivation, with a very diverse reaction of dominant weed species, which depended mainly on the year of research and the cultivation tool (plough and disc harrow). Night-time cultivation of soil reduced the number of field pennycress (*Thlaspi arvense* L.) by 24–40%, and the number of common chickweed by 24–27%. Ploughing at night reduced the number of lamb's quarters and scentless chamomile (*Matricaria inodora* L.) by 33% and 28%, respectively, and disc harrowing at night increased their number by 17% and 295%, respectively. On the other hand, the number of shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.) and annual meadow grass (*Poa annua* L.) growing on plots cultivated at night was higher by 49–134% and 1353–2846%, respectively. According to the author, too little suppression of weed infestation, especially in relations to the species characterized by high competition, does not encourage the use of this method in practice. In an experiment of Wesołowski and Cierpiała [2007], harrowing at night had no significant effect, but only a slight tendency to reduce the number and air-dry weight of weeds. Night harrowing reduced the occurrence of shepherd's purse, pale smartweed (*Polygonum lapathifolium* L.) and field pansy (*Viola arvensis* Murray), while increasing the abundance of barnyardgrass and cleavers (*Galium aparine* L.). No information is still available regarding the usefulness of nighttime tillage for weed suppression in cultivation of herbs. In a three-year experiment conducted by Dobrzański [2011], the degree of soil surface coverage with weeds evaluated 33 days after nighttime soil tillage was 26.2–53.7% lower compared to daytime tillage, and those differences disappeared after 55 days. Nighttime tillage reduced shepherd's purse infestation by approximately 50%.

The most valuable component of garden savory dry herb is essential oil, the content and composition of which varies significantly depending on the date of sowing or planting and harvesting, plant nutrition, number of harvests, type of savory population, and environmental conditions in which it is grown. Savory contains the greatest amount of essential oil at the beginning of plant flowering [Zawiślak 2008, Skubij and Dzida 2015]. In the studies conducted in Poland on Saturn cultivar, this content ranged from approximately 1.0% to 5.9% [Jadczak 2007, Zawiślak 2008, Seidler-Łożykowska et al. 2009, Dzida et al. 2015, Skubij and Dzida 2019]. Kucharski and Mordalski [2007], without giving the name of the tested savory cultivar, found oil content ranging from 4.35% to 4.86%. German and Hungarian summer savory populations cultivated in Iran produced 4.5% and 3.2% of the oil respectively [Omidbaigi and Hejazi 2004]. Essential oil obtained from summer savory cv. Saturn grown in Poland contained from 29 [Góra et al. 1996] to 59 [Skubij and Dzida 2019] compounds, with carvacrol (34.8–70.1%), γ-terpinene (21.67–40.93%), p-cymene (2.78–15.5%), α-terpinene (3.61–5.10%), myrcene (1.22–2.47%), α-thujene (1.13–1.91%), and α-pinene (0.49–1.50%) as the main components [Góra et al. 1996, Zawiślak 2008, Skubij and Dzida 2019]. In Poland, an important region of garden savory cultivation is Lubelskie Voivodeship [Newerl-Guz 2016], while information on the content of essential oil in herb produced in this region [Zawiślak 2008, Dzida et al. 2015, Skubij and Dzida 2019] and the composition of this oil [Zawiślak 2008, Skubij and Dzida 2019] is scarce and quite varied.

The objective of this study was to evaluate and compare the effect of flame weeding, spraying with glufosinate-ammonium and the use of nighttime soil tillage on weed control in summer savory grown from sowing directly into the field. Moreover, the influence of the aforementioned weed control methods on plant height, the yield of fresh savory herb and the content of essential oil in dry herb was also evaluated. An additional aim was to assess the composition of essential oil produced by hand-weeded (control) plants grown in the experiment in natural conditions of the Lublin region.

## MATERIALS AND METHODS

The experiment was conducted in the years 2011–2013 at the Felin Experimental Farm of the University of Life Sciences in Lublin, located in southeastern Poland (215 m above sea level, 51°23'N, 22°56'E). Summer savory (*Satureja hortensis* L.) cv. Saturn was cultivated on haplic Luvisol soil developed from loess deposits, containing 1.6% of organic matter and with pH (in 1 M KCl) of 6.4. Saturn cultivar is a hybrid of a selected Slovenian summer savory strain and a German population cultivated commonly in Poland [Czabajska et al. 1994]. Each year, on the day before sowing savory seeds, the experimental field was fertilized with 30 kg $N \cdot ha^{-1}$ (ammonium nitrate), 60 kg $P_2O_5 \cdot ha^{-1}$ (triple superphosphate) and 90 kg $K_2O \cdot ha^{-1}$ (concentrated potassium salt). Then, the field was divided into two halves, one of which was cultivated with a rotary tiller to the depth of 15 cm and hand raked to level the soil surface. The other half of the field was cultivated in the same way one and half hour after sunset. Inside those main plots (day tillage and night tillage), the other treatments (glufosinate-ammonium, flaming and control) were randomly arranged with 4 repetitions. On April 17th, 2011, on April 29th, 2012 and on April 22nd, 2013, summer savory seeds produced by the Polish seed company PNOS based in Ożarów Mazowiecki were seeded on the soil surface and pressed by hand in 4 rows 4 m long with 50 cm distance between the rows (8 $m^2$ plot area), maintaining the seeding rate of 8 $kg \cdot ha^{-1}$. Glufosinate-ammonium and flaming were applied on May 2nd, 2011, on May 14th, 2012, and on May 15th, 2013, which is 15, 15, and 23 days after summer savory sowing, respectively. The treatment was performed on the day when the emergence of the first summer savory seedlings was observed and weeds were at the cotyledon and first true leaves stage. Glufosinate-ammonium was sprayed at a dose of 600 $g \cdot ha^{-1}$ by means of a back-pack sprayer mounted with an XR TeeJet® nozzle at 1.5 bars pressure and 300 l of $water \cdot ha^{-1}$. Flaming was carried out by hand using a universal flamer mounted with an open tubular burner with a diameter of 50 mm using 90 kg of $propane \cdot ha^{-1}$ at 2.5 bar pressure. For the first time, the weeds were counted by species in four 20 × 50 cm frames placed randomly in interrow spaces on each plot on May 24th, 2011, on June 5th, 2012, and on June 6th, 2013, i.e. 37, 37 and 44 days after sowing, respectively. During the counting the weeds were pulled out and their fresh weight was determined. On the following day, the plots were hand weeded. Savory seedlings were counted 6 weeks after sowing in 2011 and 2012 and 7 weeks after sowing in 2013. For the second time, weed infestation was measured in the same way on June 19th, 2011, on July 4th, 2012, and on June 26th, 2013, i.e. 63, 67 and 65 days after sowing, respectively. A few days before savory harvest, a third complementary weeding was performed to remove weeds that could contaminate the herb's yield. At this date, the weeds were not counted or weighed. Every year, starting with week 7 after sowing, the height of 20 randomly selected plants in each plot was measured weekly. The last measurement was taken the day before harvest. The plants which started flowering were cut at the height of 5 cm above the soil surface, and then their fresh weight was established on July 26th, 2011, on August 1st, 2012, and on July 30th, 2013. The plants harvested from control plots were dried in natural conditions for one month in a shaded and well ventilated place at 32°C, in order to obtain air-dry herb and then determine the essential oil content of this herb.

At the beginning of October, essential oil was isolated from grated herb (only leaves and flowers without stems) of control plants by hydro-distillation in the Dering's apparatus according to the method recommended by the European Pharmacopoeia 5 [2005]. Its qualitative composition was determined by the Central Research Laboratory of the University of Life Sciences in Lublin accredited by Polish Centre for Accreditation. The oil samples were analyzed with a gas chromatograph Varian Chrompack CP-3800 coupled with mass detector Varian 4000 GC/MS/MS and flame ionization detector (FID) using VF column – 5 ms (DB-5 equivalent) according to the procedure described by Borowy and Kapłan [2022].

The field experiment was arranged in a split-plot design with three experimental factors (time of soil tillage, method of weeding and years) and four repetitions. The obtained results were analyzed statistically by means of the analysis of variance (ANOVA) involving a model for orthogonal data, while the differences between the means were estimated using the Tukey's test at a level of significance of $p = 0.05$.

## RESULTS

During 3 years of research, average monthly air temperature and monthly precipitation totals were usually higher than the long-term averages (Tab. 1 and 2),

**Table 1.** Decade, monthly and long-term (1951–2010) air temperatures (°C) in Felin Experimental Farm in the years 2011–2013

| Month | 2011 | | | | 2012 | | | | 2013 | | | | Long-term average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | decade | | | monthly average | decade | | | monthly average | decade | | | monthly average | |
| | 1-st | 2-nd | 3-rd | | 1-st | 2-nd | 3-rd | | 1-st | 2-nd | 3-rd | | |
| April | 6.2 | 9.5 | 10.6 | 8.8 | 7.8 | 9.4 | 10.8 | 9.3 | 11.4 | 9.3 | 13.5 | 11.4 | 7.4 |
| May | 9.9 | 15.1 | 19.6 | 14.9 | 11.3 | 13.3 | 13.6 | 12.7 | 13.6 | 13.1 | 14.2 | 13.6 | 13.0 |
| June | 18.2 | 20.0 | 16.2 | 18.1 | 18.0 | 16.4 | 18.8 | 17.7 | 15.3 | 14.9 | 19.1 | 16.4 | 16.3 |
| July | 17.1 | 21.0 | 19.3 | 19.1 | 17.1 | 18.8 | 18.8 | 18.2 | 19.9 | 20.5 | 19.3 | 19.9 | 17.9 |
| Average | 15.2 | | | | 14.5 | | | | 15.3 | | | | 13.7 |

**Table 2.** Decade, monthly and long-term (1951–2010) precipitation sums (mm) in Felin Experimental Farm in the years 2011–2013

| Month | 2011 | | | | 2012 | | | | 2013 | | | | Long-term |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | decade sums | | | monthly sum | decade sums | | | monthly sum | decade sums | | | monthly sum | |
| | 1-st | 2-nd | 3-rd | | 1-st | 2-nd | 3-rd | | 1-st | 2-nd | 3-rd | | |
| April | 8.8 | 5.6 | 3.0 | 17.4 | 17.6 | 35.3 | 2.9 | 55.8 | 1.1 | 1.8 | 0.0 | 2.9 | 40.2 |
| May | 13.5 | 29.9 | 37.1 | 80.5 | 57.1 | 34.7 | 9.8 | 101.6 | 3.6 | 34.7 | 32.9 | 71.2 | 57.7 |
| June | 52.4 | 25.4 | 10.0 | 87.8 | 0.0 | 19.6 | 6.3 | 25.9 | 28.2 | 32.7 | 64.6 | 125.5 | 65.7 |
| July | 48.8 | 35.0 | 3.2 | 87.0 | 39.6 | 19.3 | 18.2 | 77.1 | 15.6 | 9.8 | 31.7 | 57.1 | 83.5 |
| Total | 272.7 | | | | 260.4 | | | | 256.7 | | | | 247.1 |

**Table 3.** Effect of control method on number of weeds of each species (pcs·m$^{-2}$) growing in the experiment 34–37 days after sowing of summer savory, in the years 2011–2013

| Weed species | Daytime tillage | | | | | | | | | | | | Nighttime tillage | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | flame weeding | | | | glufosinate-ammonium | | | | control | | | | flame weeding | | | | glufosinate ammonium | | | | control | | | |
| | 2012 | 2013 | 2014 | **av.** | 2012 | 2013 | 2014 | **av.** | 2012 | 2013 | 2014 | **av.** | 2012 | 2013 | 2014 | **av.** | 2012 | 2013 | 2014 | **av.** | 2012 | 2013 | 2014 | **av.** |
| *Amaranthus retroflexus* L. | 75 | 18 | 24 | **39** | 80 | 19 | 24 | **41** | 105 | 40 | 43 | **63** | 66 | 21 | 20 | **36** | 60 | 21 | 23 | **35** | 89 | 34 | 37 | **53** |
| *Capsella bursa-pastoris* (L.) Medik. | 46 | 15 | 125 | **62** | 7 | 24 | 48 | **26** | 23 | 98 | 234 | **118** | 19 | 51 | 96 | **55** | 11 | 23 | 36 | **23** | 33 | 112 | 198 | **114** |
| *Chenopodium album* L. | 84 | 10 | 46 | **47** | 77 | 14 | 59 | **50** | 182 | 41 | 167 | **130** | 79 | 15 | 43 | **46** | 75 | 18 | 47 | **47** | 165 | 47 | 136 | **116** |
| *Conyza canadensis* (L.) Cronq. | 5 | 2 | 2 | **3** | 2 | 0 | 1 | **1** | 6 | 2 | 3 | **4** | 6 | 1 | 2 | **3** | 0 | 1 | 1 | **1** | 2 | 3 | 2 | **2** |
| *Echinochloa crus-galli* L.P. Beauv. | 2 | 0 | 3 | **2** | 0 | 0 | 1 | **1** | 3 | 2 | 6 | **4** | 0 | 0 | 2 | **1** | 0 | 0 | 0 | 0 | 3 | 1 | 2 | **2** |
| *Elymus repens* (L.) Gould | 0 | 2 | 0 | **1** | 5 | 0 | 0 | **2** | 0 | 0 | 1 | **1** | 5 | 1 | 0 | **2** | 0 | 1 | 1 | **1** | 3 | 0 | 1 | **1** |
| *Galinsoga ciliata* (Raf.) S.F. Blake | 5 | 8 | 4 | **6** | 3 | 5 | 4 | **4** | 23 | 48 | 12 | **28** | 3 | 7 | 2 | **4** | 2 | 5 | 1 | **3** | 13 | 38 | 10 | **20** |
| *Galinsoga parviflora* Cav. | 20 | 12 | 17 | **16** | 23 | 17 | 24 | **21** | 129 | 74 | 116 | **106** | 26 | 9 | 14 | **10** | 26 | 10 | 17 | **18** | 112 | 67 | 97 | **92** |
| *Gnaphalium uliginosum* L. | 0 | 5 | 0 | **2** | 0 | 3 | 0 | **1** | 0 | 11 | 0 | **4** | 0 | 1 | 0 | **1** | 0 | 3 | 0 | **1** | 0 | 12 | 0 | **4** |
| *Lamium amplexicaule* L. | 3 | 3 | 0 | **2** | 2 | 5 | 2 | **3** | 8 | 17 | 10 | **12** | 0 | 1 | 1 | **1** | 0 | 2 | 0 | **1** | 5 | 9 | 6 | **7** |
| *Matricaria chamomilla* L. | 0 | 2 | 15 | **6** | 0 | 0 | 10 | **3** | 0 | 1 | 32 | **11** | 0 | 1 | 8 | **3** | 0 | 2 | 7 | **3** | 0 | 3 | 24 | **9** |
| *Poa annua* L. | 0 | 2 | 9 | **4** | 0 | 0 | 5 | **2** | 0 | 0 | 12 | **4** | 0 | 2 | 4 | **2** | 0 | 0 | 3 | **1** | 0 | 1 | 11 | **4** |
| *Polygonum aviculare* L. | 1 | 0 | 2 | **1** | 1 | 0 | 1 | **1** | 3 | 0 | 1 | **1** | 0 | 0 | 1 | **1** | 0 | 0 | 0 | **0** | 0 | 0 | 1 | **1** |
| *Polygonum persicaria* L. | 0 | 0 | 0 | **0** | 1 | 0 | 0 | **1** | 0 | 0 | 0 | **0** | 2 | 0 | 0 | **1** | 4 | 0 | 0 | **1** | 2 | 0 | 0 | **1** |
| *Senecio vulgaris* L. | 0 | 0 | 0 | **0** | 0 | 2 | 0 | **1** | 0 | 6 | 0 | **2** | 0 | 0 | 0 | **0** | 0 | 1 | 0 | **1** | 0 | 2 | 1 | **1** |
| *Solanum nigrum* L. | 0 | 0 | 0 | **0** | 0 | 0 | 0 | **0** | 0 | 2 | 0 | **1** | 0 | 1 | 0 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| *Stellaria media* (L.) Vill. | 0 | 2 | 0 | **1** | 5 | 2 | 0 | **2** | 15 | 38 | 15 | **23** | 0 | 2 | 1 | **1** | 0 | 3 | 0 | **1** | 10 | 16 | 9 | **12** |
| *Taraxacum officinale* F.H.Wigg. | 0 | 0 | 0 | **0** | 0 | 0 | 1 | **1** | 0 | 0 | 1 | **1** | 0 | 0 | 1 | **1** | 0 | 0 | 0 | **0** | 0 | 0 | 2 | **1** |
| *Urtica urens* L. | 0 | 7 | 0 | **2** | 1 | 5 | 2 | **3** | 0 | 35 | 1 | **12** | 0 | 2 | 0 | **1** | 0 | 1 | 0 | **1** | 2 | 25 | 0 | **9** |
| *Veronica persica* Poir. | 0 | 1 | 0 | **1** | 0 | 0 | 0 | **0** | 0 | 1 | 0 | **1** | 0 | 0 | 0 | **0** | 0 | 0 | 0 | **0** | 0 | 1 | 0 | **1** |
| *Vicia angustifolia* L. | 0 | 0 | 0 | **0** | 0 | 0 | 1 | **1** | 0 | 0 | 0 | **0** | 0 | 0 | 1 | **1** | 0 | 0 | 0 | **0** | 0 | 1 | 1 | **1** |

av. – average

which favoured the cultivation of summer savory. Only too little rainfall during the few days before and after sowing was unfavorable for seed germination in 2013.

Weed emergence began 8 days after sowing in 2011 and 2012, and 13 days after sowing in 2013. About 4 weeks later, depending on the year, from 12 to 16 species of weeds, mainly annuals grew in the experiment (Tab. 3). Perennial weeds represented by couch grass and dandelion (*Taraxacum officinale* L.) occurred sporadically. The dominant species were lamb's quarter, constituting 25% of the total weed population on average, while shepherds' purse – 24%, gallant soldier (*Galinsoga parvifora* Cav.) and redroot pigweed accounted for 20% each, hairy galinsoga (*Galinsoga ciliata* (Raf.) S. F. Blake) – 5%, and common chickweed – 4%. The share of the remaining species was equal to or less than 2%, with a few occurring sporadically. Dicotyledonous weeds were definitely dominant, accounting for almost 99% of the entire population. Each year, weed flora was similar, while the average number and fresh weight of weeds growing 34–37 days after sowing in particular years differed significantly and ranged from 197 to 326 pcs·m$^{-2}$ and from 60.3 to 131.1 g·m$^{-2}$, respectively. Weed density found in 2011 and 2013 was significantly higher than in 2012, while the differences between 2011 and 2013 were not significant (Tab. 4). The methods that proved effective in weed control were flaming and spraying with glufosinate-ammonium. During treatment, they killed all weeds, but they did not prevent new weeds from emerging on the following days. Three weeks later, the number of weeds growing on plots weeded with the flame method and sprayed with glufosinate-ammonium was significantly lower by about 63 and 69%, respectively, in comparison to control, with insignificant differences between the compared methods (Tab. 4). Moreover, those weeds were much smaller (lighter in weight) than the weeds growing in control plots from the time of sowing savory. For plots culti-

**Table 4.** Effect of control method on number (pcs·m$^{-2}$) and fresh weight (g·m$^{-2}$) of weeds growing in the experiment 34–37 days after sowing of summer savory, in the years 2011–2013

| Treatment | | Number of weeds | | | | Fresh weight of weeds | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | average | 2011 | 2012 | 2013 | average |
| Day-time tillage | flame weeding | 241 | 89 | 247 | 192 | 70.1 | 22.3 | 81.9 | 58.1 |
| | glufosinate--ammonium | 208 | 96 | 183 | 162 | 62.7 | 25.8 | 62.7 | 50.4 |
| | control | 497 | 416 | 654 | 522 | 174.6 | 126.5 | 265.4 | 188.8 |
| Night-time tillage | flame weeding | 206 | 115 | 195 | 172 | 62.2 | 30.8 | 66.9 | 53.3 |
| | glufosinate-mmonium | 178 | 91 | 136 | 135 | 53.8 | 24.3 | 46.7 | 41.6 |
| | control | 439 | 372 | 538 | 450 | 159.7 | 114.3 | 218.2 | 164.1 |
| Average | | 295 | 197 | 326 | 272 | 92.7 | 57.3 | 123.6 | 92.7 |
| Average for day- and nighttime tillage | | number: 292 (day), 252 (night); weight: 99.1 (day), 83.6 (night) | | | | | | | |
| Average for weed control methods | | number: 182 (flame weeding), 149 (glufosinate-ammonium), 486 (control); weight: 55.7 (flame weeding), 46.0 (glufosinate ammonium), 176.5 (control) | | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| $LSD_{0.05}$ (number) | | | $LSD_{0.05}$ (weight) | | |
| Time of tillage (A): n. s. | A × B: n. s. | A × B × C: n. s. | Time of tillage (A): n. s. | A × B: n. s. | A × B × C: n. s. |
| Years (B): 83.9 | A × C: n. s. | | Years (B): 43.48 | A × C: n. s. | |
| Methods of weeding (C): 119.7 | B × C: n. s. | | Methods of weeding (C): 63.71 | B × C: n. s. | |

vated at night, those values were approximately 14% and 13% lower, respectively, compared to daytime cultivation, with insignificant differences (Tab. 4). An average number of lamb's quarter in plots cultivated at night was about 8% lower than in plots cultivated during the day. Similarly, the number of shepherds' purse, gallant soldier, redroot pigweed, hairy galinsoga, and common chickweed was lower by 7, 16, 13, 29, and 46% respectively.

Approximately 3–4 weeks after the first assessment of weed infestation and subsequent weeding, there were, depending on the year, from 11 to 18 species of weeds, including all dominating so far (Tab. 5). Three species that occurred sporadically, that is groundsel (*Senecio vulgaris* L.), black nightshade (*Solanum nigrum* L.), and birdeye speedwell (*Veronica persica* Poir.) disappeared, while in 2013 annual knavel (*Scleranthus annuus* L.) marked its presence. Moreover, the share of barnyardgrass, and in 2012–2013 also the share of marsh cudweed (*Gnaphalium uliginosum* L.) in the total weed population increased considerably to 24% and 10%, respectively, while the share of the hitherto dominant species decreased. Every year, the total number of weeds growing after the first weeding was considerably lower compared to primary weed infestation, while their fresh weight was higher (Tab. 6). In the second assessment, like in the first, a significant influence of the year of study was found, with no effect of the time of soil tillage on the total number and fresh weight of weeds. However, in the second assessment, the influence of the weed control method disappeared. Moreover, the number of the dominant weeds growing at that time on plots tilled at night was very similar to that of day-tilled plots (Tab. 6).

Each year, savory cultivation period lasted for approximately 14 weeks. The emergence of savory which began 12, 14 and 22 days after sowing, corresponding to the research years, was very uneven, and lasted for 3 consecutive weeks. The average number of seedlings growing in 1 running meter 6–7 weeks after sowing was 40 in 2011, 48 in 2012 and 38 in 2013, which corresponds to 80, 96 and 76 seedlings per square meter, respectively. The emergence in 2012 was significantly higher than in the remaining two years, which differed insignificantly (Tab. 7). Directly after emergence, the seedlings were very small and they grew slowly. Faster growth started at the end of May and continued until harvest. Seven weeks after sowing savory plants reached the height of approximately 10 cm. Over the next 7 weeks until harvest, a weekly height gain was fairly steady, of about 6 to 10 cm. At that time, plants formed numerous side shoots which gradually covered the soil surface. Soil coverage by savory assessed 40, 60 and 80 days after sowing was approximately 5, 20 and 80%, respectively. At harvest, an average height of plants ranged from 50.1 to 66.7 cm and was significantly dependent on the year of study and independent of weed management (Tab. 7). Plants cultivated in 2012 were significantly higher (65.0 cm) than those cultivated in 2011 (59.8 cm) and 2013 (51.9 cm), with their height differing insignificantly.

The yields of fresh herb ranged from 43.4 kg·100 $m^{-2}$ to 62.1 kg·100 $m^{-2}$ and were significantly dependent only on the years of research (Tab. 7). The yield harvested in 2012 (58.8 kg·100 $m^{-2}$) was significantly higher than the yields in 2011 (50.4 kg·100 $m^{-2}$) and 2013 (45.7 kg·100 $m^{-2}$), which differed insignificantly.

Dry savory herb contained, in order of research years, 2.39–2.46%, 1.85–1.98% and 2.06–2.15% essential oil, respectively. This content was significantly dependent on the year of research and independent of the two other studied factors (Tab. 8). Summer savory cultivated in 2011 produced significantly more oil than in other years. In oil distilled from control plants, 35 compounds were detected, which accounted for 99.85% of the total. Carvacrol (45.19–46.75%) and γ-terpinene (34.59–39.88%) had by far the largest share. Much smaller, although clearly visible, was the share of α-terpinene (4.75–4.81%), p-cymene (2.71–3.98%), myrcene (1.45–1.99%) and α-thujene (1.42–1.80%). The average share of the remaining components did not exceed 1%, with only trace amounts of octen-3-ol<-1>, octanol<3->, α-guaiene, aromadendrene and caryphyllene oxide (Tab. 8).

## DISCUSSION

In the experiment, savory was grown on fertile soil prepared in accordance with agrotechnical recommendations [Rumińska 1991, Mordalski 2018] and under favourable weather conditions. Air temperatures, usually higher than the long-term averages (Tab. 1), as well as a greater sum of rainfalls and their fairly

**Table 5.** Effect of control method on number of weeds of each species (pcs·m$^{-2}$) growing in the experiment 3–4 weeks after first weeding, in the years 2011–2013

| Weed species | Day-time tillage | | | | | | | | | | | | Night-time tillage | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | flame weeding | | | | glufosinate-ammonium | | | | control | | | | flame weeding | | | | glufosinate-ammonium | | | | control | | | |
| | 2011 | 2012 | 2013 | **av.** | 2011 | 2012 | 2013 | **av.** | 2011 | 2012 | 2013 | **av.** | 2011 | 2012 | 2013 | **av.** | 2011 | 2012 | 2013 | **av.** | 2011 | 2012 | 2013 | **av.** |
| *Amaranthus retroflexus* L. | 11 | 5 | 16 | **15** | 12 | 8 | 12 | **11** | 14 | 7 | 13 | **11** | 15 | 5 | 16 | **12** | 17 | 4 | 19 | **11** | 15 | 4 | 13 | **11** |
| *Capsella bursa-pastoris* (L.) Medik. | 12 | 7 | 20 | **18** | 7 | 9 | 14 | **10** | 6 | 13 | 18 | **13** | 9 | 12 | 22 | **14** | 8 | 12 | 24 | **12** | 9 | 15 | 21 | **15** |
| *Chenopodium album* L. | 47 | 2 | 3 | **26** | 51 | 3 | 1 | **18** | 54 | 4 | 2 | **20** | 53 | 4 | 2 | **20** | 55 | 3 | 1 | **20** | 52 | 5 | 1 | **19** |
| *Conyza canadensis* (L.) Cronq. | 0 | 1 | 0 | **1** | 0 | 1 | 0 | **1** | 0 | 1 | 1 | **1** | 0 | 2 | 1 | **1** | 0 | 0 | 0 | **0** | 0 | 1 | 0 | **1** |
| *Echinochloa cruss-galli* (L.) P. Beauv. | 24 | 21 | 53 | **45** | 18 | 20 | 50 | **29** | 21 | 23 | 55 | **33** | 20 | 21 | 56 | **32** | 18 | 21 | 75 | **30** | 24 | 24 | 54 | **34** |
| *Elymus repens* (L.) Gould | 1 | 0 | 1 | **1** | 0 | 1 | 0 | **1** | 1 | 0 | 1 | **1** | 0 | 1 | 0 | **1** | 1 | 0 | 1 | **1** | 1 | 2 | 0 | **1** |
| *Galinsoga ciliata* (Raf.) S.F. Blake | 12 | 3 | 8 | **11** | 15 | 2 | 6 | **8** | 12 | 2 | 7 | **7** | 17 | 3 | 5 | **8** | 12 | 1 | 6 | **6** | 14 | 2 | 9 | **8** |
| *Galinsoga parviflora* Cav. | 22 | 10 | 27 | **28** | 21 | 7 | 23 | **17** | 20 | 11 | 29 | **20** | 22 | 7 | 28 | **19** | 18 | 4 | 29 | **14** | 19 | 10 | 25 | **18** |
| *Gnaphalium uliginosum* L. | 0 | 7 | 22 | **13** | 0 | 7 | 34 | **14** | 0 | 12 | 31 | **14** | 0 | 11 | 21 | **11** | 0 | 7 | 41 | **12** | 0 | 16 | 26 | **14** |
| *Lamium amplexicaule* L. | 0 | 2 | 1 | **1** | 0 | 1 | 2 | **1** | 0 | 3 | 1 | **1** | 0 | 3 | 0 | **1** | 0 | 3 | 1 | **1** | 0 | 3 | 1 | **1** |
| *Matricaria chamomilla* L. | 0 | 0 | 12 | **6** | 0 | 0 | 14 | **5** | 0 | 1 | 16 | **6** | 0 | 2 | 11 | **4** | 0 | 1 | 17 | **4** | 0 | 2 | 15 | **6** |
| *Poa annua* L. | 1 | 2 | 1 | **2** | 0 | 0 | 1 | **1** | 2 | 1 | 2 | **2** | 1 | 3 | 3 | **2** | 1 | 2 | 1 | **1** | 1 | 3 | 1 | **2** |
| *Polygonum aviculare* L. | 0 | 1 | 0 | **1** | 1 | 0 | 0 | **1** | 0 | 1 | 1 | **1** | 0 | 0 | 1 | **1** | 0 | 1 | 0 | **1** | 1 | 0 | 1 | **1** |
| *Polygonum persicaria* L. | 1 | 0 | 0 | **1** | 0 | 0 | 1 | **1** | 1 | 0 | 1 | **1** | 1 | 0 | 0 | **1** | 1 | 0 | 1 | **1** | 1 | 0 | 1 | **1** |
| *Scleranthus annuus* L. | 0 | 0 | 5 | **2** | 0 | 0 | 6 | **2** | 0 | 0 | 7 | **2** | 0 | 0 | 7 | **2** | 0 | 0 | 11 | **3** | 0 | 0 | 8 | **3** |
| *Stellaria media* (L.) Vill. | 0 | 4 | 1 | **2** | 0 | 2 | 0 | **1** | 0 | 4 | 1 | **2** | 0 | 14 | 1 | **5** | 0 | 22 | 0 | **7** | 0 | 21 | 1 | **7** |
| *Taraxacum officinale* F.H.Wigg. | 0 | 3 | 1 | **1** | 0 | 5 | 1 | **2** | 0 | 6 | 0 | **2** | 0 | 4 | 0 | **1** | 0 | 3 | 0 | **1** | 0 | 6 | 0 | **2** |
| *Urtica urens* L. | 0 | 4 | 0 | **1** | 1 | 3 | 0 | **1** | 0 | 7 | 1 | **3** | 1 | 6 | 1 | **2** | 1 | 4 | 0 | **2** | 1 | 6 | 1 | **2** |
| *Vicia angustifolia* L. | 0 | 0 | 1 | **1** | 0 | 0 | 0 | **0** | 0 | 1 | 1 | **1** | 0 | 1 | 0 | **1** | 1 | 0 | 0 | **1** | 0 | 1 | 0 | **1** |

av. – average

even distribution during the vegetation period (Tab. 2) favoured the growth of savory plants. Only in 2013, drought in April and the first ten days of May delayed the emergence of cultivated plant and weeds.

Results obtained in the experiment show that earlier emerging, more numerous and faster growing weeds gained advantage in the field from the beginning of savory growing. Moreover, a lack of emergence of savory delineating the rows of crop made it difficult to use mechanical weeding tools during the first 2–3 weeks after sowing. Like in the case of lemon balm [Borowy and Kapłan 2022], this was the most difficult period during savory cultivation to protect against weeds. Therefore, it was very useful to spray the sowing with glufosinate-ammonium or to flame weeds when first savory seedlings appeared. Although some of them were destroyed, it did not have a significant effect on the final number of emergence or on the herb yield (Tab. 5). In practice, determining the exact date of treatment is quite troublesome as it requires daily inspection of the field starting a few days after the crop was established. In the experiment, the earliest savory emergence was observed 12 days after sowing, which was much earlier than reported by Senderski [2009], Mordalski [2018] and Dzida et al. [2015]. However, in 2013, which was characterized by very little rainfall in April (2.9 mm) and the first ten days of May (1.1 mm) (Tab. 2), the first savory emergence appeared only 22 days after sowing. Rain falling several days after savory emergence started can prevent flaming or spraying with glufosinate-ammonium, thus hindering further weeding. Both treatments can be applied earlier, but with less effectiveness. Complete destruction of weeds at the beginning of savory emergence created good conditions for small and slowly growing seedlings, which started to grow faster only about 2 weeks later, becoming more resistant to weed competition. Flaming and glufosinate-ammonium do not show soil residual activity [Senseman 2007, Knežević 2016] and therefore 3 weeks after treatment new weeds emerged. However, they were less than half as many and considerably smaller than in control plots (Tab. 4), which made it much easier to perform the first weeding. Both of these methods are of very short duration, though usually fewer weeds emerge after their use than after mechanical weeding, during which the buried weed seeds are moved to the soil surface, where they germinate [Knežević 2016]. Both discussed methods, which are characterized by a total and contact activity [Ascard 1995, Sensemann 2001], destroyed young leaves of dandelion and couch grass growing in the experiment, but they did not damage their underground organs, from which new leaves soon sprouted. For this reason, they will be of little use in the fields heavily infested with perennial weeds. It should also be noted that flaming is not very effective on soils infested with grasses [Ascard 1995]. In the experiment, there were two such annual species: barnyardgrass and annual meadow grass; however, their share in the total weed population during the first five weeks after savory sowing was very small (Tab. 3) and therefore flaming efficiency was good (Tab. 4). Numerous emergence of barnyardgrass was not recorded until the following weeks (Tab. 5). In Poland, this weed is referred to as thermophilic and it usually emerges in late spring [Dobrzański 1999]. It often accompanies herbal crops [Kordana et al. 2002, Krawiec et al. 2019, Borowy and Kapłan 2020, Borowy and Kapłan 2022], many of which similarly come from the regions with warmer climates [Senderski 2009]. High efficiency of flaming and spraying with glufosinate-ammonium in weed control, observed in the experiment, is generally consistent with the results obtained by Ascard [1995], Kordana et al. [1997], Knezevic et al. [2009, 2014, 2014a], and Borowy and Kapłan [2022]. Large gas consumption during the flaming of weeds in the experiment was similar to that reported by Borowy and Kapłan [2022] and was within the upper dose range tested by Ascard [1995] and Knezevic et al. [2009, 2014, 2014a]. It would probably be lower if a specialized burner was used provided with a flame shield to keep thermal energy close to the soil surface [Storeheier 1994, Knežević 2016]. Herbs are a very large and diverse group of plants and flaming could be used, also as a post-emergence treatment, in some of them, but this requires further research.

Under conditions of the present experiment, soil tillage at night had no significant effect on the number and fresh weight of weeds growing about 5 weeks after savory sowing, and only a tendency was observed to reduce weed infestation, which is consistent with the results obtained by Adamiak [2004], Wesołowski and Cierpiała [2007], as well as with the outcomes of one of Ascard's [1994] 3 experiments and one of Gerhards et al. [1998] 11 experiments. Similarly, a slight reduction in the number of lamb's quarter observed in the experiment on the plots cultivated at night is in line with the findings of the Ascard [1994] study, but it is only partly consistent with the data noted by Adamiak [2004]. A fairly strong response of common chickweed to night time tillage found in the experiment was greater than that observed by Adamiak [2004] and smaller than that described by Ascard [1994]. A weak reaction of redroot pigweed and shepherd's purse to this tillage observed in the experiment is inconsistent with that noted by Gallagher and Cardina [1998], Adamiak [2004], and Dobrzański [2011]. On the other hand, a lack of effect of nighttime tillage on weeds growing in the experiment 63–67 days after savory sowing is in line with the results of Dobrzański's [2011] research. Results of this experiment, compared with the literature data, show a large variability in the effect of night time soil tillage on weeds and they confirm the opinion of Dobrzański [2011] and Hartmann [2016] that it depends on many factors, and therefore it is difficult to predict [Andersson et al. 1997] and may be of minor importance in weed management [Gallagher and Cardina 1998, Adamiak 2004]. Appreciating its non-chemical nature and sometimes good performance [Ascard 1994, Gerhards et al. 1998, Dobrzański 2011], one can only recommend testing this method in agrotechnical conditions of a particular farm.

Secondary weed infestation was characterized by a smaller number and greater fresh weed weight than primary infestation (Tab. 4, Tab. 6), which is consistent with the results of other studies [Chmielowiec and Borowy 2005, Jelonkiewicz and Borowy 2005]. Lower density and good weather conditions in June favored the growth of weeds, but also of savory plants, which at that time reached the height of 20–30 cm, developed side shoots, and covered about 20% of the soil surface, thus limiting weed infestation. The second weeding was therefore easier to perform despite the fact that the tested weed control methods did not work anymore. During the second half of the vegetation period, savory grew rapidly and finally covered about 80% of soil surface. Nevertheless, it was necessary to perform the third complementary weeding in order to remove the weeds that could contaminate the herb yield and cause its loss of commercial value.

**Table 6.** Effect of control method on number (pcs·m$^{-2}$) and fresh weight (g·m$^{-2}$) of weeds growing in the experiment 3–4 weeks after first weeding, in the years 2011–2013

| Treatment | | Number of weeds | | | | Fresh weight of weeds | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | average | 2011 | 2012 | 2013 | average |
| Day-time tillage | flame weeding | 131 | 72 | 172 | 125 | 117.9 | 65.8 | 189.2 | 124.3 |
| | glufosinate-ammonium | 126 | 69 | 165 | 120 | 114.2 | 62.2 | 182.3 | 119.6 |
| | control | 134 | 97 | 188 | 140 | 121.8 | 88.4 | 207.6 | 139.3 |
| Night-time tillage | flame weeding | 139 | 99 | 174 | 137 | 126.4 | 89.2 | 191.4 | 135.7 |
| | glufosinate-ammonium | 131 | 88 | 155 | 125 | 118.7 | 79.4 | 171.5 | 123.2 |
| | control | 137 | 121 | 178 | 145 | 125.3 | 109.9 | 196.9 | 144.0 |
| Average | | 133 | 91 | 172 | 132 | 120.7 | 82.5 | 189.8 | 131.0 |

| | |
|---|---|
| Average for day- and nighttime tillage | number: 128 (day), 136 (night); weight: 127.7 (day), 134.3 (night) |
| Average for weed control methods | number: 131 (flame weeding), 122 (glufosinate-ammonium), 143 (control)<br>weight: 130.0 (flame weeding), 121.4 (glufosinate ammonium), 141.7(control) |

| $LSD_{0.05}$ (number) | | | $LSD_{0.05}$ (weight) | | |
|---|---|---|---|---|---|
| Time of tillage (A): n.s. | A × B: n.s. | A × B × C: n.s. | Time of tillage (A): n.s. | A × B: n.s. | A × B × C: n.s. |
| Years (B): 43.2 | A × C: n.s. | | Years (B): 59.7 | A × C: n.s. | |
| Methods of weeding (C): n.s. | B × C: n.s. | | Methods of weeding (C): n.s. | B × C: n.s. | |

The number of savory emergence was significantly greater in 2012, which was characterized by the highest rainfall in April (55.8 mm) and on the first ten days of May (57.1 mm), i.e. after sowing the seeds and during the emergence of savory. Plants growing in higher densities were taller and produced a higher herb yield (Tab. 7). Good weather and soil conditions favored further growth of savory plants, which reached an average height, depending on the year, from 51.9 to 65.0 cm (Tab. 7). This height was similar to that determined by Senderski [2009] and Hamidpour et al. [2014] but much greater than that reported by Czabajska et al. [1994], Rumińska [1991] and Mordalski [2018]. Plant height depends on many factors, especially on the weather and the soil conditions in which the plant is grown [Yang et al. 2021]. Despite a favorable arrangement of these conditions, the yields of fresh herb harvested in the experiment were usually lower than those obtained in Poland by other authors who used higher a seeding rate [Seidler-Łożykowska et al. 2015], cultivated savory from transplants [Martyniak-Przybyszewska and Majkowska-Gadomska 2007, Zawiślak 2008] or in narrower row spacing [Dzida et al. 2015]. In the experiment, the upper limit of the recommended row spacing [Mordalski 2018] was used in order to better observe and measure changes in weed infestation. In the remaining articles cited [Czabajska et al. 1994, Kucharski and Mordalski 2007, Skubij and Dzida 2019], description of cultivation method was

**Table 7.** Emergence of summer savory (pcs·m$^{-1}$), plant height at harvest (cm), yield of fresh herb (kg·100 m$^{-2}$), and content of essential oil (%) in grated herb in dependence on weed management in the years 2011–2013

| Treatment | | Emergence | | | | Plant height | | | | Yield of fresh herb | | | | Content of oil | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | mean | 2011 | 2012 | 2013 | mean | 2011 | 2012 | 2013 | mean | 2011 | 2012 | 2013 | mean |
| Day-time tillage | flame weeding | 38 | 49 | 36 | 41.0 | 59.6 | 64.0 | 50.3 | 58.0 | 48.4 | 55.4 | 44.6 | 49.5 | 2.43 | 1.86 | 2.08 | 2.12 |
| | glufos.-ammon. | 40 | 48 | 37 | 41.7 | 60.1 | 65.7 | 54.8 | 60.2 | 50.1 | 57.6 | 48.1 | 51.9 | 2.39 | 1.98 | 2.11 | 2.16 |
| | control | 42 | 51 | 40 | 44.3 | 59.2 | 64.5 | 50.8 | 58.2 | 47.4 | 62.1 | 45.5 | 51.7 | 2.46 | 1.85 | 2.15 | 2.15 |
| Night-time tillage | flame weeding | 39 | 45 | 35 | 39.7 | 61.0 | 66.7 | 53.8 | 60.5 | 46.9 | 59.4 | 43.4 | 49.9 | 2.41 | 1.94 | 2.06 | 2.14 |
| | glufos.-ammon. | 38 | 48 | 41 | 42.3 | 59.3 | 64.1 | 51.8 | 58.4 | 52.6 | 61.5 | 45.2 | 53.1 | 2.43 | 1.89 | 2.09 | 2.14 |
| | control | 44 | 49 | 38 | 43.7 | 59.4 | 65.0 | 50.1 | 58.2 | 56.7 | 56.8 | 47.4 | 53.6 | 2.44 | 1.93 | 2.13 | 2.17 |
| Mean | | 40.2 | 48.3 | 37.8 | 42.1 | 59. 8 | 65.0 | 51.9 | 58.9 | 50.4 | 58.8 | 45.7 | 51.6 | 2.43 | 1.91 | 2.10 | 2.15 |

| | |
|---|---|
| Mean for the day- and nighttime tillage emergence: | 42.3 (day), 41.9 (night); yield: 51.0 (day), 52.2 (night); height: 58.8 (day), 59.0 (night); oil content: 2.14 (day), 2.15 (night) |
| Mean for the weed management | emergence: 40.4 (flam.), 42.0 (gluf.-am.), 44 (contr.); yield: 49.7 (flam.), 52.5 (gluf.-am.), 52.7 (contr.);<br>height: 59.3 (flam.), 59.3 (gluf.-am.), 58.2 (contr.); oil content: 2.13 (flam.), 2.15 (gluf.-am.), 2.16 (contr.) |

| $LSD_{0.05}$ | |
|---|---|
| Time of tillage (A) | emergence: n.s.; yield: n.s.; height: n.s.; oil content: n.s.; A × B: n.s., A × C: n.s., B × C: n.s., A × B × C: n.s. |
| Years (B) | emergence: 6.14; yield: 5.71; height: 4.78; content: 0.096; A × B: n.s., A × C: n.s., B × C: n.s., A × B × C: n.s. |
| Methods of weeding (C) | emergence: n.s.; yield: n.s.; height: n.s.; oil content: n.s.; A × B: n.s., A. × C: n.s., B × C: n.s., A × B × C: n.s. |

**Table 8.** Composition of essential oil produced by summer savory plants hand weeded (% share of total components) in the years 2011–2013

| Name of the compound | IR | 2011 | | 2012 | | 2013 | | Mean (%) |
|---|---|---|---|---|---|---|---|---|
| | | % | e.u.% | % | e.u.% | % | e.u.% | |
| α-Thujene | 925 | 1.80 | ±0.03 | 1.42 | ±0.01 | 1.77 | ±0.02 | 1.66 |
| α-Pinene | 934 | 0.95 | ±0.01 | 0.89 | ±0.00 | 0.94 | ±0.01 | 0.93 |
| Camphene | 948 | 0.09 | ±0.01 | 0.08 | ±0.01 | 0.08 | ±0.00 | 0.08 |
| Sabinene | 971 | 0.06 | ±0.00 | tr. | | tr. | | 0.02 |
| β-Pinene | 978 | 0.31 | ±0.01 | 0.32 | ±0.01 | 0.34 | ±0.01 | 0.32 |
| Octen-3-ol<1-> | 980 | tr. | | tr. | | – | | tr. |
| Myrcene | 989 | 1.99 | ±0.03 | 1.45 | ±0.01 | 1.69 | ±0.02 | 1.71 |
| Octanol<3-> | 993 | tr. | | – | | – | | tr. |
| α-Phellandrene | 1005 | 0.41 | ±0.00 | 0.42 | ±0.01 | 0.48 | ±0.01 | 0.44 |
| p-Mentha-1(7),8-diene | 1008 | 0.06 | ±0.00 | tr. | | tr. | | 0.02 |
| α-Terpinene | 1016 | 4.81 | ±0.07 | 4.75 | ±0.04 | 4.78 | ±.06 | 4.78 |
| p-Cymene | 1025 | 3.98 | ±0.08 | 2.71 | ±0.04 | 2.85 | ±0.03 | 3.18 |
| Limonene | 1029 | 0.27 | ±0.00 | 0.37 | ±0.00 | 0.40 | ±0.01 | 0.35 |
| β-Phellandrene | 1031 | 0.17 | ±0.00 | 0.26 | ±0.02 | 0.31 | ±0.03 | 0.25 |
| β-Ocimene (Z) | 1037 | 0.08 | ±0.00 | – | | tr. | | 0.03 |
| β-Ocimene (E) | 1046 | tr. | | tr. | | 0.06 | ±0.00 | 0.02 |
| γ-Terpinene | 1059 | 34.59 | ±0.15 | 39.88 | ±0.21 | 37.05 | ±0.26 | 37.17 |
| c-Sabinene hydrate | 1068 | 0.32 | ±0.01 | 0.11 | ±0.00 | 0.12 | ±0.00 | 0.18 |
| Terpinolene | 1086 | 0.06 | ±0.00 | tr. | | 0.07 | ± 0.00 | 0.04 |
| t-Sabinene hydrate | 1101 | 0.21 | ±0.01 | 0.06 | ±0.00 | 0.08 | ±0.00 | 0.12 |
| Borneol | 1170 | 0.09 | ±0.00 | 0.08 | ±0.00 | 0.09 | ±0.01 | 0.09 |
| Terpinen-4-ol | 1180 | 0.29 | ±0.01 | 0.20 | ±0.00 | 0.30 | ±0.01 | 0.26 |
| A-Terpineol | 1193 | 0.06 | ±0.00 | tr. | | 0.06 | ±0.00 | 0.04 |
| Thymol | 1292 | 0.32 | ±0.02 | 0.08 | ±0.01 | tr. | | 0.13 |
| Carvacrol | 1302 | 46.74 | ±0.21 | 45.19 | ±0.24 | 46.66 | ±0.14 | 46.22 |
| Carvacrol acetate | 1373 | – | | tr. | | 0.08 | ±0.00 | 0.03 |
| Caryophyllene<E-> | 1421 | 1.22 | ±0.02 | 1.14 | ±0.01 | 1.03 | ±0.00 | 1.14 |
| α-Guaiene | 1440 | – | | tr. | | tr. | | tr. |
| Aromadendrene | 1441 | – | | tr. | | tr. | | tr. |
| α-Humulene | 1454 | 0.06 | ±0.00 | tr. | | 0.06 | ±0.00 | 0.04 |
| Viridiflorene | 1493 | – | | tr. | | tr. | | tr. |
| Bicyclogermacrene | 1495 | 0.11 | ±0.00 | 0.07 | ±0.00 | 0.06 | ±0.00 | 0.08 |
| α-Bisabolene (Z) | 1503 | 0.05 | ±0.00 | – | | tr. | | 0.02 |
| β-Bisabolene | 1511 | 0.75 | ±0.02 | 0.40 | ±0.00 | 0.45 | ±0.01 | 0.53 |
| Caryophyllene oxide | 1584 | tr. | | – | | tr. | | tr. |
| Total | | 99.85 | | 99.88 | | 99.81 | | 99.85 |

IR – retention indices [Van den Dool and Kratz 1963] e.u. – expanded uncertainty tr. – content < 0.05% or 0.001 mg·ml$^{-1}$

too general to explain the differences in the yield of savory. Methods of weeding investigated in the experiment had no effect on this feature (Tab. 7).

In the experiment, savory herb was harvested at the beginning of the flowering of plants, when they contained the most essential oil [Zawiślak 2008, Skubij and Dzida 2019]. The content of this compound in dry herb, depending on the treatment, ranged from 1.85 to 2.39% (Tab. 5) and it was close to the lower content of range 2.3–3.3% determined by Zawiślak [2008] and the upper content range 1.56–1.87% found by Dzida et al. [2015] for the same Saturn cultivar grown in the same experimental farm, but in different years. A significant influence of various weather conditions occurring in individual years on the content of essential oil was also found in this experiment. The greatest amount of essential oil was contained in herb harvested in 2011, which was characterized by the highest air temperature and the lowest amount of rainfall during the last ten days before harvesting (Tab. 1 and 2). Other authors, growing savory in other regions, found a much lower [Jadczak 2007] or a much higher content of this compound [Kucharski and Mordalski 2007, Seidler-Łożykowska et al. 2015, Skubij and Dzida 2019]. The obtained results and literature data evidence a large variability in the content of essential oil in savory herb conditioned by many factors. On the other hand, the methods of weed control tested in the experiment had no significant effect on this trait, which is consistent with the results of Pank [1992] and Borowy and Kapłan [2022]. The number of 35 components detected in savory essential oil was slightly higher than that determined by Góra et al. [1996], similar to that detected by Zawiślak [2008] and much smaller than that found by Skubij and Dzida [2019], which could be at least in part due to the differences between the analytical methods used. The share of individual components in the oil was more or less similar to their share in oils studied by the authors mentioned above. It can only be assumed that, as in the experiment carried out by Borowy and Kapłan [2022], the weed control methods studied in this experiment also had no effect on this trait. It is worth noting that the dominant component carvacrol is currently viewed as a potential bioherbicide [Yankova-Tsvetkova et al. 2020].

## CONCLUSIONS

1. Results and observations gathered in this experiment show that in the cultivation of summer savory, due to a long and uneven emergence and an initially slow growth of seedlings, it is necessary to perform the weeding at least twice, supplemented by a removal of individual weeds growing later which could contaminate the herb yield. They also show that weed control is the most difficult part of this crop agrotechnics and that the time of emergence is the period of its greatest sensitivity to weed competition.

2. Flaming using 90 kg propane·ha$^{-1}$ and spraying with glufosinate-ammonium 600 g·ha$^{-1}$ after the emergence of weeds and the first savory seedlings effectively protected savory sowing against weeds in a critical period for this crop.

3. Soil cultivation with a rotary tiller to the depth of 15 cm one and a half hours after sunset did not affect the occurrence of the dominant species of weeds, nor the total number or fresh weight of weeds growing in the experiment.

4. The studied methods of weeding did not affect the emergence, plant height and yield of savory herb, or the content of essential oil in dry herb and the composition of this oil.

## ACKNOWLEDGMENTS

The research was financially supported by the Polish Ministry of Science and Higher Education from funds designed for the statutory activities of the Department of Vegetable Crops and Medicinal Plants, University of Life Sciences in Lublin. The authors would like to thank Mr. Jerzy Zioło for help with field trias and Mr. Marek Niewiadomy for help in collecting scientific literature related to the scope of this research.

## REFERENCES

Adamiak, E. (2004). Fotobiologiczna regulacja zachwaszczenia w rzepaku ozimym [Photobiological control of weeds in winter rape]. Acta Sci. Pol., Agricultura, 3(1), 203–208.

Ascard, J. (1995). Effects of flame weeding on weed species at different developmental stages. Weed Res., 35(5), 397–411.

Andersson, L., Milberg, P., Noronha A. (1997). Germination responses of weed seeds to light, light of short duration and darkness after stratification in soil. Swedish J. Agric. Res., 27, 113–120.

Borowy, A., Kapłan, M. (2022). Evaluating chemical and thermal weed suppression in lemon balm (*Melissa officinalis* L.) cultivation. Acta Sci. Pol. Hortorum Cultus, 21(1), 39–56. https://doi.org/10.24326/asphc.2022.1.4

Borowy, A., Kapłan, M. (2020). Evaluating mustard seed meal for weed suppression in borage (*Borago officinalis* L.) cultivation. Acta Agrobot., 73(2), 7328. https://doi.org/10.5586/aa.7328

Carrubba, A., Militello, M. (2013). Nonchemical weeding of medicinal and aromatic plants. Agron. Sustain. Dev., 33, 551–561. https://doi.org/10.1007/s13593-012-0122-9

Chmielowiec, P., Borowy, A. (2005). Changes in weed community infesting common bean crop. Folia Hortic., 17(1), 3–10.

Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91, Article 12, Plant production rules, 1(g), 9.

Czabajska, W., Seidler-Łożykowska, K., Kaźmierczak, K. (1994). Hodowla cząbru ogrodowego (*Satureja hortensis* L.) [The breeding of new variety of savory (*Satureja hortensis* L.)]. Herba Pol., 90(4), 168–172.

Dobrzański, A. (1999). Ochrona warzyw przed chwastami [Protection of vegetables from weeds]. PWRiL, Warszawa, 13.

Dobrzański, A. (2011). Reakcja nasion chwastów segetalnych na uprawę roli wykonywaną nocą [Segetal weed seeds response to night-time soil tillage]. Post. Nauk Rol., 2, 9–19.

Dzida, K., Zawiślak, G., Nurzyńska-Wierdak, R., Michałojć, Z., Jarosz, Z., Pitura, K., Karczmarz, K. (2015). Yield and quality of the summer savory herb (*Satureja hortensis* L.) grown for a bunch harvest. Acta Sci. Pol. Hortorum Cultus, 14(3), 141–156.

European Pharmacopoeia (2005). 5th ed. Council of Europe, Strasbourg, 217–218, 2205–2206.

Gallagher, R.S., Cardina, J. (1998). The effect of light environment during tillage on the recruitment of various summer annuals. Weed Sci., 46(2), 214–216. https://doi.org/10.1017/S0043174500090445

Gerhards, R., Juroszek, P., Klümper, H., Kübauch, W. (1998). Möglichkeiten zur photobiologischen Unkrautregulierung auf Ackerschlägen. Pflanzenbauwissenschaften, 2(2), 91–96.

Góra, J., Lis, A., Lewandowski, A. (1996). Chemical composition of the essential oil of cultivated summer savory (*Satureja hortensis* cv. Saturn). J. Essent. Oil Res., 8(4), 427–428. https://doi.org/10.1080/10412905.1996.9700656

Hamidpour, R., Hamidpour, S., Hamidpour, M., Shahlari, M., Sohraby, M. (2014). Summer savory: from the selection of traditional applications to the novel effect in relief, prevention, and treatment of a number of serious illnesses such as diabetes, cardiovascular disease, Alzheimer's disease, and cancer. J. Tradit. Complement. Med., 4(3), 140–144.

HRAC. (2020). Herbicide resistance action committee. www.plantprotection.org/HRAC/MOA.htlm

Hartmann, K.M. (2016). Photo-biological control of weed germination. Med. Aromat. Plants, 5(3), 1000247. https://doi.org/10.4172/2167-0412.1000247

Jadczak, D. (2007). Effect of sowing date on the quantity and quality of the yield of summer savory (*Satureja hortensis* L.) grown for a bunch harvest. Herba Pol., 53(3), 22–27.

Jelonkiewicz, M., Borowy, A. (2005). Effect of rye mulch on growth of weeds under no-tillage cultivation. Allelopathy J., 16(1), 113–120.

Juroszek, P., Neuhoff, D., Köpke, U. (2017). Night-time tillage revisited: the delayed soil desiccation process in night-time tilled plots may promote unexpected weed germination. Weed Res., 57(4), 213–217. https://doi.org/10.1111/wre.12256

Knezevic, S.Z. (2017). Flame weeding in corn, soybean and sunflower. Proc. 8th Int. Conf. Inform. Comm. Technol. Agric., Food Environ., Chania, Greece, 21–24 Sept., 390–394.

Knezevic, S., Datta, A., Bruening, C., Gogos, G. (2014). Propane fueled flame weeding in corn, soybean and sunflower, pp. 38. http://www.agpropane.com/ContentPageWithLeftNav.aspx?id=1916

Knezevic, S.Z., Datta, A., Ulloa, S.M., (2009). Tolerance of selected weed species to broadcast flaming at different growth stages. In: Proc. 8th EWRS Workshop on Physical and Cultural Weed Control, Cloutier, D.C. (ed.). Zaragoza, Spain, 98–103.

Knezevic, S., Stepanovic, S., Datta, A. (2014a). Growth stage affects response of selected weed species to flaming propane. Weed Technol., 28(1), 233–242. https://doi.org/10.1614/WT-D-13-00054.1

Knežević, S.Z. (2016). Flame weeding as an alternative tool for weed management in agronomic crops: revisiting the old concept. Acta Herb., 25(2), 69–80.

Kordana, S., Kucharski, W.A., Mordalski, R., Mikołajewicz, M. (2002). Porównanie skuteczności chwastobójczej graminicydów Fusilade Forte 150 EC i Fusialde

Super 125 EC w roślinach zielarskich [Comparison of efficacy of Fusilade Forte 150 EC and Fusilade Super 124 EC in medicinal plant crops]. Prog. Plant Prot., 42(2), 601–603.

Krawiec, M., Borowy, A., Dzida, K. (2019). Chemical and nonchemical control of weeds in the cultivation of lemon balm for seeds. Acta Sci. Pol. Hortorum Cultus, 18(5), 83–89. https://doi.org/10.24326/asphc.2019.5.8

Kucharski, W.A., Mordalski, R. (2007). Wpływ sposobu odchwaszczania plantacji na plonowanie wybranych gatunków roślin olejkowych [An influence of the different methods of weeding on the selected aromatic plant yielding]. Prog. Plant Prot./Post. Ochr. Rośl., 47(3), 173–176.

Martyniak-Przybyszewska, B., Majkowska-Gadomska, J. (2007). Wpływ wybranych czynników agrotechnicznych na plon cząbru ogrodowego (*Satureja hortensis* L.) i lebiodki pospolitej (*Origanum vulgare* L.) [The effect of some agrotechnical factors on the yields of savory (*Satureja hortensis* L.) and common majoram (*Origanum vulgare* L.)]. Ann. UMCS, sec. EEE, Horticultura, 16, 113–117.

Mordalski, R. (2018). Cząber ogrodowy (*Satureja hortensis* L.) [Summer savory (*Satureja hortensis* L.)]. In: Uprawa ziół. Poradnik dla plantatorów [Cultivation of herbs. Guide for growers], Kołodziej, B. (ed.). PWRiL, Warszawa, 166–170.

Nemming, A. (1994). Costs of flame cultivation. Acta Hortic., 372, 205–212. https://doi.org/10.17660/ActaHortic.1994.372.24

Newerli-Guz, J. (2016). Uprawa roślin zielarskich w Polsce [The cultivation of herbal plants in Poland]. Rocz. Nauk. SERiA, 18(3), 268–274.

Omidbaigi, R., Hejazi, M. (2004). Essential oil content and compositions of *Satureja hortensis* of two different origins. J. Essent. Oil Res., 7(2), 175–178. https://doi.org/10.1080/0972-060X.2004.10643387

Pank, F. (1992). The influence of chemical weed control on quality characters of medicinal and aromatic plants. Acta Hortic., 306, 145–154. https://doi.org/10.17660/ActaHortic.1992.306.14

Praczyk, T., Skrzypczak, G. (2004). Herbicydy [Herbicides]. PWRiL, Poznań, 67–68.

Rumińska, A. (1983). Rośliny lecznicze [Medicinal plants]. PWN, Warszawa, 310–319.

Rumińska, A. (ed.), (1991). Poradnik plantatora ziół [A herb grower's guide]. PWRiL, Poznań, 133–138.

Seidler-Łożykowska, K., Mordalski, R., Kucharski, W., Golcz, A., Kozik, E., Wójcik, J. (2009). Economic and qualitative value of the raw material of chosen species of medicinal plants from organic farming. Part III. Yield and quality of herb and seed yield of summer savory (*Satureja hortensis* L.). Acta Sci. Pol. Agric., 8(4), 47–53.

Senderski, M.E. (2009). Zioła. Praktyczny poradnik o ziołach i ziołolecznictwie [Herbs. Practical guide to herbs and herbal medicine]. K.E. Liber, Warszawa, 253–255.

Senseman, S.A. (ed.), (2007). Herbicide Handbook, 9th ed., Lawrence, K.S., WSSA, Champaign, Illinois, pp. 458.

Skubij, N., Dzida, K. (2019). Essential oil composition of summer savory (*Satureja hortensis* L.) cv. Saturn depending on nitrogen nutrition and plant development phases in raw material cultivated for industrial use. Ind. Crops Prod., 135, 260–270. https://doi.org/10.1016/j.indcrop.2019.04.057

Storeheier, K.J. (1994). Basic investigations into flaming for weed control. Acta Hortic., 372, 195–204.

Van Den Dool, H., Kratz, P.D. (1963). A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J. Chromat., 11, 463–471.

Wesołowski, M., Cierpiała, R. (2007). Wykorzystanie zjawiska fotoblastyzmu w regulacji zachwaszczenia pszenicy jarej [The usage of fotoblastizm effect in control of spring wheat weed infestation]. Prog. Plant Prot./Post. Ochr. Rośl., 47(3), 296–300.

Yang, Q., Lin, G., Lv, H., Wang, C., Yang, Y., Liao, H. (2021). Environmental and genetic regulation of plant height in soybean. BMC Plant Biology, 21, 63. https://doi.org/10.1186/s12870-021-02836-7

Yankova-Tsvetkova, E., Nikolova, M., Aneva, I., Stefanova, T., Berkov, S. (2020). Germination inhibition bioassay of extracts and essential oils from plant species. C. R. Acad. Bulg. Sci., 73(9), 1254–1259. https://doi.org/10.7546/CRABS.2020.09.09

Zawiślak, G. (2008). Plonowanie i jakość ziela cząbru ogrodowego (*Satureja hortensis* L.) odmiany Saturn uprawianej z rozsady [Yield and quality of herb of garden savory (*Satureja hortensis* L.) cv. Saturn grown from transplants]. Zesz. Prob. Post. Nauk Rol., 527, 327–333.