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Non-chemical control methods of Sosnowsky's hogweed (*Heracleum sosnovskyi* Manden.)

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Abstract

Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.) is an invasive species becoming an increased problem in the Europe including the Baltic region. It is an aggressive weed that poses a threat to human health. It is extremely difficult to control this plant, especially in the locations where chemical control is impossible. The purpose of the research was to evaluate the efficiency of non-chemical control methods of cutting and shading for 1st- and 2nd-year *H. sosnowskyi* plants as well as thermal control by heating with water steam at different growth stages. The study was carried out in Ukraine over the period of 2013–2020. To test the efficacy of cutting and shading aboveground parts of *H. sosnowskyi*, two field trials were conducted. Second-year plants were able to regenerate their aboveground part. Cutting of the 2nd-year shoots of *H. sosnowskyi* reduced the aboveground mass by 89.8–90.3%. An effective control of *H. sosnowskyi* was root removal in the 10 cm soil layer. Removal of the aboveground part of plant was less effective because of a high *H. sosnowskyi* regeneration, and the efficacy of control significantly decreased. The 1st-year plants of *H. sosnowskyi* at the 4-leaf stage were sensitive to covering by a plastic film. Shading for 30 days on juvenile plants ensured the sufficient efficacy of control. Thermal control (at a steam temperature of ≥95°C) was most efficient when *H. sosnowskyi* plants were at the cotyledon up to 4-leaf stage.

Using of two non-chemical methods could have an effective control of 1st- and 2nd-year plants of *H. sosnowskyi*.

Keywords: *Heracleum sosnowskyi*, invasive weeds, mechanical control, cutting, thermal control, shading.

Introduction

Representatives of *Heracleum* L. are widespread in the world flora: there are 69 species growing mainly in Eurasia (Jahodová et al., 2007; Pyšek et al., 2007; Gubar, Koniakin, 2021). The active distribution of *H. sosnowskyi* as an invasive species began around the mid-1980s. It occurred almost simultaneously in different parts of Ukraine (Grygus et al., 2018) as well as in other parts of Europe. In Europe, it has rapidly established in a variety of habitats, particularly in spaces along rivers, forest edges, roadsides, and urban areas (Gudžinskas, Rašomavičius, 2005; Jahodová et al., 2007; Baležentienė et al., 2013; Barret, Harder, 2017; Panasenko, 2017; Andreasen et al., 2018; Dalke et al., 2018; Gołos, 2018; Čerevková et al., 2020). In the Baltic countries, *H. sosnowskyi* is considered a harmful and dangerous weed since the 1980s. In 1986 in Latvia and in 1987 in Estonia, it was recognised as an aggressive weed, primarily due to the negative impact on the taste of meat and milk and partly due to risks to human and animal health (Mežaka et al., 2016; Zihare, Blumberga, 2017). In Belarus, the number of growing places of *H. sosnowskyi* increases by 30% every year, while the area of existing populations increases by 20–25% (Yakimovich et al., 2013). According to Grygus et al. (2018), in Ukraine, the largest concentration of *H. sosnowskyi* populations was found in the southern and western parts of the city of Rivene. *Heracleum mantegazzianum* is one of problematic plant invasions in North America as well (Cuddington et al., 2022).

Analysis of the distribution of *H. sosnowskyi* in Ukraine by land categories showed that almost half (49%) of the population of this species is concentrated in the areas of industrial, transport, communications, energy, defence, and other purposes, primarily in roadsides. A significant part of the population was found on agricultural lands (23%) and lands of settlements, horticultural societies, and dacha cooperatives (26%) (Protopopova et al., 2002). Due to its large size, biomass accumulation rate, and a high degree of plasticity, *H. sosnowskyi* may reduce in a short time the size of populations of many local plant species, especially in meadow and river plant communities, until they are completely displaced (Gubar, Koniakin, 2021). In Ukraine, *H. sosnowskyi* is gradually

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capturing new territories (Grygus et al., 2018). It grows especially thick in abandoned fields and other places with disturbed natural vegetation.

As a result, the rhizomatous plants become replaced by *H. sosnowskyi* with taproot system, which is not able to form a dense turf and retain the soil layer leading to soil erosion (Tarasevich, Orlov, 2013; Mykhalyuk et al., 2017). Having an extremely high reproductive capacity and adaptability to the environment conditions, *H. sosnowskyi* was distributed over long distances with wind, water flows, road, and rail transport, as the majority of seeds shatter around the source plant (up to 75−80 thousand seeds per plant) (Chernyak, 2018).

H. sosnowskyi is a monocarpic plant and may grow in a vegetative stage for several years, although the plant dies after producing seeds once. Studies on the soil seed-bank of *H. sosnowskyi* in Lithuania have demonstrated that seed density directly affects the density of seedlings in spring (Gudžinskas, Žalneravičius, 2018). For alien species, the ability to develop a persistent seed bank is associated with their ability to naturalise and become invasive.

At the beginning of its expansion, *H. sosnowskyi* was found exclusively in strongly anthropically disturbed ecotopes along roadsides, on the outskirts of settlements, wastelands, landfills, around farms, and in ravines. In the second period, it significantly increased the number and area of population and vegetation with some of the areas merging into solid large focuses (Godefroid, 2001). A major factor contributing to the successful invasion of *H. sosnowskyi* may be anthropogenic dispersal together with its individual characteristics which include environmental tolerance, high fertility, phenotypic plasticity, cold resistance, and the ability to occupy new biotopes. This plant species has turned into transformers and supplanted the native species significantly reducing the diversity (Osipova et al., 2021). According to other researchers (Grzezicka, 2022), only 15−20 species of mostly weed ruderal species of herbaceous plants can survive growing with *H. sosnowskyi*. This species displaces species of forage and medicinal plants from floodplain phytocenoses.

The life cycle of *H. sosnowskyi* plants occurs in two variants. In the first variant, the plant develops as a biennial species. In the first year, it forms a large, branched, and strong root system with a rosette of leaves, and in the following year, it develops a shoot with inflorescences producing a significant number of seeds. In another variant, individuals may survive for several years as a perennial plant and can bloom and bear fruit after 3–7 years. *H. sosnowskyi* is a cold-resistant plant, and in the first year of life, may withstand −4–7°C temperature. Starting from the second year, the plants can withstand −25°C, and when covered by a layer of snow, even up to −45°C (Dalke et al., 2015). At the same time, plants are demanding light, badly withstand shading and cover crops, and they need moist soils (Dalke et al., 2015; Betekhtina et al., 2019).

Human activities contribute to the spread of *H. sosnowskyi*, as the plants often grow in roadside ditches and on roadsides and other ecotopes of ruderal nature. *H. sosnowskyi* plants go from transformed habitats to natural ones, where they occupy rather stable positions and are characterised by high phytocenotic activity often acting as a dominant or co-dominant (Sužiedelytė Visockienė et al., 2020). It is recognised that *H. sosnowskyi* increases the area occupied by its plants (new individuals) by 10% annually, but there is information about more intensive distribution (Grygus et al., 2018).

Controlling invasive species of *H. sosnowskyi* requires the use of a wide arsenal of various techniques. It is necessary to strengthen the phytosanitary control of motor transport and railways, settlements, green areas, roadside, and protective strips. To select the optimal control method, it is necessary to take into account the ecological and coenotic needs of such species and the peculiarities of economic activity in the region (Tautges et al., 2017; Koryznienė et al., 2019).

Mowing is available among the mechanical methods of controlling *H. sosnowskyi* plants. If weeds are mowed after seed formation, fresh seeds will enter the soil. In 10−12 days after the pollination, seeds have already fully formed embryos that are able to develop into new plants. An effective way is to cut inflorescences during the period of budding and early flowering and burn plants during the period of seed maturation. An effective method suitable for any age of plants is to cut them to a depth of at least 10−15 cm that leads to their complete dying off. However, this technique can be performed in small areas. In addition, such an operation is potentially dangerous for people performing it, as it is easy to get stained with juice and get severe dermatoses in different parts of the body (Jakubowicz et al., 2012; Klima, Synowiec, 2016; Lyon et al., 2017).

It is difficult to control the number of *H. sosnowskyi* plants due to its biological peculiarities, the high level of seed productivity, and the formation of the seed stock. One of the ways to control this species is a chemical method (Jodaugienė et al., 2018). However, the use of pesticides is not always allowed, especially in the protected areas or places close to water sources, therefore, alternative methods must be obtained.

Thermal weed control technology plays an important role in managing weeds under different agrosystems. This technology is based on the principles of plant thermal energy exchange at high temperatures (Sirvydas et al., 2002). Traditionally, plants are heated by a torch of fire or hot gases that are products of the combustion of natural gas or petroleum products. High temperatures lead to the denaturation of enzyme proteins and their loss of catalytic properties. As a result of such a disorder of metabolic processes, plants die (Davies, Shelly, 2007). Thermal control (heating) of *H. sosnowskyi* juvenile plants could be one of the possible methods for residential areas, where the use of herbicides is limited. Ecological traits of *H. sosnovskyj* are responsible for their wide and various role in the environment, and no effective method to eradicate this weed has been found (Grzezicka, 2022), therefore, methods for the control of this plant-invader are highly required.

The purpose of this research was to study the methods of non-chemical weed control for both 1st- and 2nd-year plants of *H. sosnowskyi* in the conditions of Forest-Steppe zone of Ukraine in chernozem.

Material and methods

The field experiment was carried out in the years 2013–2020 in the Bila Tserkva Research and Breeding Station located in the Central Forest-Steppe of Ukraine. The dominating soil type is medium to deep chernozem with a low humus content, various degrees of leaching, and a distinct natural structure and a good nutrient provision. The soil of the experimental field was typical coarse leached medium-loam chernozem (WRB, 2015) with a depth of humus horizon from 100 to 120 cm and the humus content in the arable (0–30 cm) layer of 3.9%, which is typical of low-humus chernozem. It was characterised by the following agrochemical parameters: depth of the humus horizon 50–60 cm; Ca and Mg carbonates occur at a depth of 50–65 cm; hydrolytic acidity 1.5–1.8 mg eq. 100 g^{-1} of soil; the content of alkaline-hydrolysed nitrogen (by the Cornfield's method) 120–140 mg kg^{-1}, nitrate 14.2–19.6 mg kg^{-1}; mobile phosphorus and exchangeable potassium (by the Chirikov's method) 180–240 and 90–120 mg kg^{-1} of soil, respectively; soil acidity neutral or close to neutral.

During the years of the experiment (2013–2020), weather conditions showed some deviations from the average long-term indicators, but in general, it was favourable for the growth and development of most species of crops and weeds including Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.). Rainfall distribution during the year was not even: mostly in the warm season, especially in mid-summer (July). In some years, the summer was dry, which negatively affected the growth and development of plants. The sum of active temperatures (the sum of temperatures above 10°C for the growing season) varied from 2500°C to 2800°C, and the amount of precipitation per year was 521 mm. The average long-term air temperature was +7.4°C (generalised data for the last 25 years).

Efficiency assessment for different weed control methods for *H. sosnowskyi* involved several aspects.

Mechanical control of H. sosnowskyi plants. The study involved sowing seeds of *H. sosnowskyi* and their vegetation during the year. The following year, in the spring, experimental treatments were established. At each plot, 20 plants of *H. sosnowskyi* were selected. The experiment was performed in four replications. Each treatment consisted of 80 weed plants. The experimental design included the following options: 1) without cutting (control); with cutting: 2) 5 cm below the soil surface, 3) 10 cm below the soil surface, 4) 0 cm from the soil surface, 5) at a height of 5 cm above the soil surface, 6) at a height of 10 cm above the soil surface, and 7) at a height of 15 cm above the soil surface. The cuttings were carried out after the shoots had reached a height of 20 cm (Figure 1).

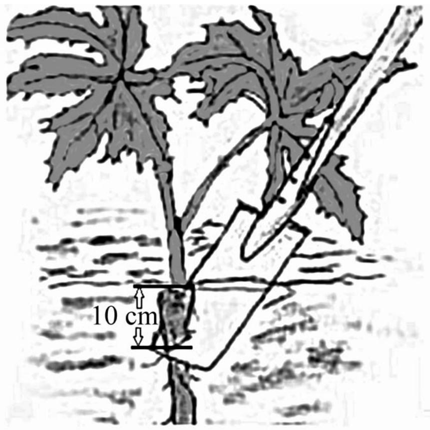


Figure 1. Mechanical cutting of *Heracleum sosnowskyi* plants (picture of O. Ivaschcenko)

Control of H. sosnowskyi plants by shading. In the field experiment, *H. sosnowskyi* plants of both the 1st (grown from seeds) and second year were used. A single plot included 20 plants. The experiment was carried out in four replications, i.e., each treatment included 80 plants of *H. sosnowskyi*. The first cutting of plants was carried out on shoots of 20 cm in height. To assess the ability to control 2nd-year plants of *H. sosnowskyi* by the shading, in the second year of vegetation, field experiments were conducted with 20 plants on the plot in four replications, i.e., each treatment included 80 plants of *H. sosnowskyi* (Table 1).

Thermal control of H. sosnowskyi plants. The study of the response of weed plants to the induced thermal control was performed using a portable steam generator. First-year plants of *H. sosnowskyi* were treated at different growth stages with steam at a temperature of 100°C at a distance of 10–12 cm. The speed of the stream flow was 5 m s^{-1}. The treatment lasted 0.5–0.8 seconds. The field experiment was carried out in seven replications, the gross plot area was 3.0 m^2, and the assessed plot area 2.0 m^2. The placement of the plots was regular. To heat weed plants during vegetation, a portable steam generator was used. The temperature was measured using a non-contact laser thermometer.

Table 1. Scheme of mechanical cutting and shading for a different growing period of *Heracleum sosnowskyi* plants

The first year					
Without cutting and shading (control)	Shading from 2-leaf stage for 15 days	Cutting at 2-leaf stage + shading for 15 days	Cutting at 6-leaf stage + shading for 15 days	Cutting at 6-leaf stage + shading for 30 days	
The second year					
Without cutting and shading (control)	Cutting + shading for 15 days	Cutting + shading for 30 days	Cutting + shading for 45 days	Cutting + shading for 60 days	Cutting + shading for 30 days + repeated after 30 days

To obtain plants at various development stages at the time of treatment with steam, sowing in the spring was carried out with an interval of 5 days. Water steam treatment of seedlings of *H. sosnowskyi* plants was performed at the following development stages: 1) cotyledon, 2) 2-leaf, 3) 4-leaf, 4) 6-leaf, and 5) 8-leaf. Estimation of the level of water steam efficiency at different temperatures was determined according to the scheme: 1) without induced heat stress (control); induced heat stress by steam at a temperature of: 2) 80°C, 3) 85°C, 4) 90°C, 5) 95°C, and 6) 100°C. This issue was investigated in a separate experiment. After the emergence of *H. sosnowskyi* plants in plots, the plant density was adjusted to 50 plants per 1 m^{-2}. Accordingly, in each treatment of the experiment, 700 plants were used. The treatment of plants with steam in the procedures was always carried out in one day.

Statistical analysis. Averages were calculated for each plot and used in the calculation of mean. The assessment data were processed by analysis of variation (ANOVA) with Fisher's least significant difference (LSD) test. The treatment effects were considered significant at $P < 0.05$.

Results and discussion

Heracleum sosnowskyi is widespread in Ukraine. It is dangerous and must be controlled because such plants are characterised by a high biological productivity, competitiveness, and viability and form a seed stock that retains the ability to germinate in natural conditions for up to five years. It is difficult to effectively control the distribution of such plants in residential areas and agricultural lands. In order to develop effective and environmentally safe methods of controlling plants of *H. sosnowskyi*, this study have included not only the clarification of the biology of weed but also the possibility of targeted control and destruction.

Mechanical control of H. sosnowskyi plants. The experiment was carried out with *H. sosnowskyi* plants of the second year of growth. In the spring, after the beginning of the active vegetation of weed plants that had successfully overwintered and reached a height of 20 cm, they were cut mechanically, as described in the Material and Methods section. The results are given in Table 2.

The subsequent vegetation of weed plants in most experiments was successful. In the control plot, where the cutting was not performed (treatment 1), the plants successively went through all stages of organogenesis. At the generative stage of organogenesis (flowering), the height of *H. sosnowskyi* reached an average of 2.73 m and formed a leaf area of 15734 cm^2 of plant.

Carrying out mechanical cutting of plants at the ground level required the restoration of lost aboveground mass and the re-formation of stems and leaves. The average height of new stems was 1.39 m, which was 49.1% less than in the control treatment. In addition to reducing the ability to form the height of shoots, the possibility of the formation of aboveground mass in pre-cut plants also decreased. The average aboveground mass was 412 g m^{-2}, i.e., compared to that of treatment 1, the decrease was 90.3%. The leaf area of *H. sosnowskyi* plants at the time of flowering was 913 cm^{-2} plant, which was 94.2% less compared to that of treatment 1. There was a tendency of decreasing the height of shoots that regrew along with increasing cutting height (5, 10, and 15 cm above the soil surface). Part of the aboveground mass of such plants, primarily their leaf apparatus, was preserved and continued to function successfully. The plants did not need to fully restore it. Accordingly, the height of plant shoots after regrowth was in the range from 147 to 157 cm. Green mass formation after cutting and subsequent regrowth also decreased, but the decrease was in the range from 89.8% to 90.1% of the green mass of weeds formed in treatment 1. A similar trend was observed in the formation of the leaf area of weeds. Cutting of the aboveground mass of *H. sosnowskyi* plants significantly reduced the level of their biological productivity, but they successfully continued their vegetation and went through the next stages of organogenesis.

Table 2. Regenerative ability of 2nd-year plants of *Heracleum sosnowskyi* after mechanical cutting (2013–2015)

Treatment No.	Cutting scheme	Shoot regrowth cm	Green mass of plants g m^{-2}	Leaf area cm^2 per plant
1.	Without cutting (control)	273 a	4241 a	15734 a
2.	5 cm below the soil surface	74 d	327 c	811 d
3.	10 cm below the soil surface	0 e	0 d	0 d
4.	0 cm from the soil surface	139 dc	412b	913 c
5.	5 cm above the soil surface	147 c	421 b	927 c
6.	10 cm above the soil surface	153 b	425 b	1010 b
7.	15 cm above the soil surface	157 b	432 b	1017 b

Note. Different letters indicate significant differences between treatments ($P \leq 0.05$); n – 20 plants per plot (80 plants in each treatment) were assessed.

Mechanical cutting of weed plants below the soil surface considers the morphological features of the location of apical buds on the underground parts of plants in the soil (cryptophytes). Cutting plants at a depth of 5 cm below the soil surface significantly reduces their regenerative ability to restore lost aboveground mass and buds. The most developed apical buds in plants were lost because of mechanical damage. After cutting, regrowth was observed only in those adventitious buds that remained intact on the underground parts of *H. sosnowskyi* plants. By the end of the growing season, new weed shoots had an average height of 74 cm, i.e., a decrease was 72.9% compared to that of treatment 1. Plants formed the aboveground mass on the average of 327 g m^{-2}, which made up 92.3% of the regrowth in the control treatment. The use of such a technique significantly reduced the biological potential of *H. sosnowskyi* plants but showed a significant drawback: it did not provide destruction of weed plants. In subsequent growing seasons, they could gradually restore their high competitiveness (Klima, Synowiec, 2016).

The experimental scheme included cutting weeds at 10 cm below the soil surface (treatment 3). This depth of cutting made damage to almost all buds of vegetation restoration.

The method of cutting deprived weeds their regenerative ability. The underground part, which had a well-developed root system and a supply of plastic substances, lost contact with the buds to restore vegetation because of cutting. The buds present in the upper part had no connection with the plastic depot and the root system. Accordingly, both parts of the plants in the following period were not viable and gradually died off. Similar results were obtained by Klima and Synowiec (2016). According to those authors, the full control over *H. sosnowskyi* can be achieved by cutting the roots of plants up to 5 years old at 15 cm above the soil surface.

Control of H. sosnowskyi plants by shading. For the successful implement the processes of photosynthesis, a prerequisite for green plants is access to the flow of solar energy and photosynthetically active radiation (PAR) that have light waves with a length from 380 to 710 nm. The simplest way to achieve weakening or complete extinction of weeds including *H. sosnowskyi* is to block the processes of photosynthesis by shading plants with a lightproof screen (Nielsen et al., 2007).

The experiment evaluated the response of *H. sosnowskyi* plants of the first year of vegetation (grown from seeds) to the duration of shading and their ability to overcome mechanical damage (cutting). After 15 days of the shading, 7.7% of plants continued their growth, and the main part of *H. sosnowskyi* plants died. In the plots, where weed plants were cut at the 6-leaf stage and covered with a black film, by the end of shading, all experimental plants died. The ability of *H. sosnowskyi* plants to survive in the first year of vegetation depended primarily on the availability and volume of plastic substances stock and the duration of shading. In the plants of *H. sosnowskyi* of the second year of vegetation, at the initial stage of ontogenesis, in the conditions of the almost complete absence of light, energy distress occurred, which manifested itself in the loss of the ability of plants to form a new organic matter.

For the formation of annual shoots and leaves, stocks of plastic substances of the previous growing season in the underground (perennial) parts of the plant were used, since the previous ones were lost because of the first cutting. In treatment 2, where plants were shaded for 15 days, the formation of green mass in the next growing season made up 4702 g m^{-2}. The plants withstood the increasing duration of shading to 30, 45, and 60 days, but such conditions in the absence of photosynthesis reduced their ability in the next growing season to form an aboveground mass almost linearly (Table 3).

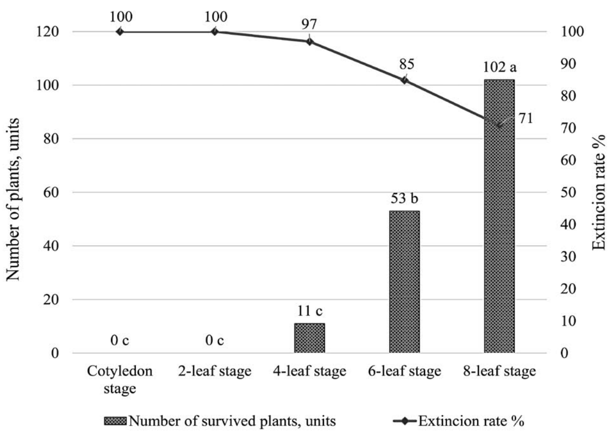
Table 3. The ability of second-year *Heracleum sosnowskyi* plants to form an aboveground mass (g m^{-2}) after cutting and shading (2015–2020)

Treatment (first year)	Period of shading, days (second year)			
	15	30	45	60
1. Without cutting and shading (control)	all plants grow successfully			
2. Shading from 2-leaf stage for 15 days	4702 ab	4333 c	3910 a	2880 a
3. Cutting at 2-leaf stage + shading for 15 days	4705 ab	4544 a	1638 b	793 b
4. Cutting at 6-leaf stage + shading for 15 days	4755 a	4386 bc	1480 c	0 c
5. Cutting at 6-leaf stage + shading for 30 days	4597 b	4491 ab	1585 bc	0 c

Note. Different letters indicate significant differences between treatments ($P \leq 0.05$); n – 20 plants per plot (80 plants in each treatment) were assessed.

Treatments with two consecutive cuttings were carried out (the second cutting of aboveground mass after 30 days of shading after the first cutting) and subsequent shading for another 30 and 45 days resulted in partial extinction (67.5%, or 54 plants out of 80). Weed plants, where the duration of re-shading after the second cutting was 45 days, died off completely.

Determination of the sensitivity of H. sosnowskyi plants to the thermal control at different developmental stages. The treatment of *H. sosnowskyi* seedlings with hot steam led to the complete disorganisation of metabolic processes in the tissue cells of young plants. The thickness of the tissues of seedlings at the cotyledon stage in the aboveground mass of plants is insignificant, and they were quickly heated to the temperature close to 100°C. The transfer of heat from the surface of the plants to the depth was well carried out by the tissues themselves, because they contain a lot of water in this period of organogenesis. Usually, the water content in the tissue cells of *H. sosnowskyi* seedlings varies from 80% to 94% of their total weight (Słowinski et al., 2022). The generalised results are given in Figure 2.

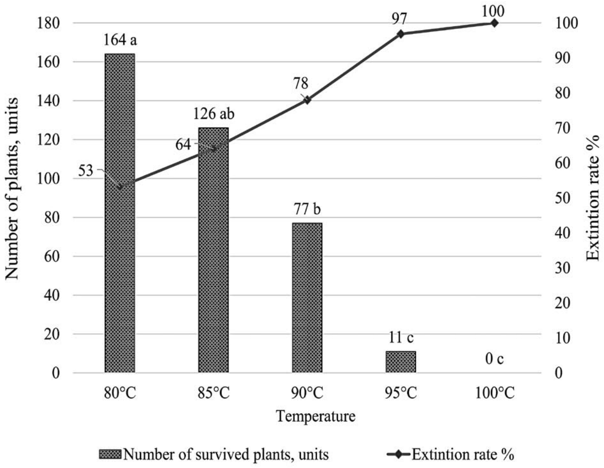


Note. Different letters indicate significant differences between treatments ($P \leq 0.05$).

Figure 2. Stage-related sensitivity (percentage of survival) of *Heracleum sosnowskyi* plants to thermal control (2013–2015)

The increase at the stages of weed plants development (2-leaf formation) increased their contact with the flow of hot steam, but the mass of plants gradually increased and the ability to resist a rapid heating of tissues in depth increased. *H. sosnowskyi* plants died off completely. At the 4-leaf stage, the plant sensitivity to the action of high temperatures in comparison with the previous stage showed a tendency to decrease. The extinction rate at this stage was 97% (339 plants). At the same time, 11 plants (3% of the total number of plants in the treatment) survived and continued to grow. The treatment of weed seedlings with hot steam at the 6-leaf stage revealed a significant increase in their resistance to heat. This effect can be explained by the accumulation of larger above-ground mass, which required more heat energy to heat, and the complicated process of heating plant tissues due to their thickness, especially heating meristem tissues at growth points located on the stem, both apical and collateral (Baue et al., 2020). Accordingly, the extinction rate was lower than before. At the 6-leaf stage, 85% of seedlings died off. The water steam treatment of *H. sosnowskyi* plants at the 8-leaf stage was less effective in comparison with the previous stages of development; the extinction rate was 71% (248 out of 350).

Determination of the sensitivity of H. sosnowskyi to the thermal control at different temperatures. In the process of studying the peculiarities of the sensitivity of *H. sosnowskyi* seedlings to the action of water steam, peculiarities of plant sensitivity at different developmental stages were investigated. However, the level of sensitivity of weed plants to heat is influenced by the steam flow temperature, i.e., the level of heating of the seedlings and their ability to survive in the next growing period. In all the treatments of the experiment, the stage of development of *H. sosnowskyi* plants was the same, 4-leaf stage. The heating temperature of the plants with steam was monitored by a special non-contact laser thermometer. The steam flow temperature of 80°C significantly affected the plant ability to continue the vegetation in 53% of seedlings heated to a temperature of 80°C; at the same time, it should be noted that 164 plants (47%) survived (Figure 3).



Note. Different letters indicate significant differences between treatments ($P \leq 0.05$).

Figure 3. Sensitivity of *Heracleum sosnowskyi* plants at the 4-leaf stage to thermal control (2013−2015)

Increasing the steam temperature to 85°C provided more severe heat stress to plants and, accordingly, a tendency to increase the number of plants that could not overcome such a negative impact. As a result, the plant extinction rate was 64% (126 out of 350 survived). The application of higher (90°C) steam temperature increased the extinction rate resulted from heat stress: 78% of plants used in the experiment died off. Heating *H. sosnowskyi* seedlings to a temperature of 95°C led to an extinction rate of 97%: only 11 of the 350 plants survived. This means that the level of efficiency of the steam action on the seedlings of *H. sosnowskyi* plants was at the level of a highly efficient herbicide. Increasing the temperature to 100°C led to the complete extinction, i.e., 100% of weed plants ceased their vegetation.

Summarising the results of the effectiveness of water steam (up to 80°C) action on the seedlings of *H. sosnowskyi*, it can be argued that the applied thermal stress can significantly affect young plants. As a result, some of them gradually died off, others after a long period of suppression (from 7 to 20 days) survived and continued to grow. Increasing the steam temperature and the level of heat influence of *H. sosnowskyi* seedlings to 95°C provided an increase in heat stress in the young plants and, accordingly, a higher rate of their extinction. The overall reduction in the number of *H. sosnowskyi* seedlings because of heating the plants at the 4-leaf stage to a temperature of 95°C reached 96.3%.

A prerequisite for the successful control of annual plants of *H. sosnowskyi* in crops is the regular inspection of crops and the determination of species composition of weeds at the cotyledon stage in order to timely detect *H. sosnowskyi* seedlings and carry out weeds control measures (Sužiedelytė Visockienė et al., 2020). On the other hand, the decision to remove invaders should have been supported by the results of interdisciplinary research, because some animals, due to the lack of natural habitats, might not be able to recreate relationships already established with this plant (Grzezicka, 2022).

Conclusions

1. Mechanical control. Cutting only 2nd-year-old *Heracleum sosnowskyi* plants reduces their ability to form an aboveground mass by 89.8–90.3%. It is advisable to cut 2nd-year plants 10 cm below the soil surface, which provides the effective control of plants and prevents their subsequent regrowth.

2. Shading technique. First-year shoots are quite sensitive to their complete shading, especially at the early stages of development, from four to six leaves. Shading of juvenile annual weeds for more than 30 days ensured their extinction. Shading of plants at the subsequent stages of their organogenesis was less efficient. To significantly reduce the biological productivity of annual weeds after the formation from six to ten leaves, the minimum period of shading should be at least 60 days. For 2nd-year plants, the addition of shading to two successive cuttings accelerated the depletion of their reserves of plastic substances and ensured extinction after 45–60 days of subsequent shading.

3. Thermal control. The sensitivity of the aboveground mass of 1st-year shoots to the action of water steam decreases with increasing stages of weed plants development. The extinction rate varied from 100% (cotyledon stage) to 85% (6-leaf stage). The efficiency of the thermal control of shoots (4-leaf stage) also depended on the parameters of steam. At a steam temperature of 80°C, 53% of weed plants died. Increasing the steam temperature to 95°C led to the 96.3% extinction rate.

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Sosnovskio barščio (*Heracleum sosnovskyi* Manden.) necheminiai kontrolės metodai

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Santrauka

Sosnovskio barštis (*Heracleum sosnowskyi* Manden.) yra invazinė piktžolių rūšis, kurios plitimas tampa vis didesne problema Europoje ir Baltijos regione. Tai agresyvus ir žmonėms pavojingas augalas, kurio plitimą sunku suvaldyti, ypač tose vietovėse, kur negalima cheminė kontrolė. Tyrimo tikslas – įvertinti vienamečių ir daugiamečių augalų pjovimo, uždengimo ir terminės kontrolės vandens garais metodų efektyvumą. Tyrimas atliktas 2013–2020 m. Ukrainos bioenergetinių augalų ir cukrinių runkelių institute. Siekiant patikrinti pjovimo aukščio ir trukmės uždengimo efektyvumą Sosnovskio barščių masės ir generacinėse dalyse, buvo vykdyti du lauko eksperimentai. Pjaunant daugiamečius Sosnovskio barščius, augalų antžeminė masė sumažėjo 89,8–90,3 %. Augalų kontrolė buvo veiksminga pakertant šaknis dirvoje 10 cm gylyje. Pjaunant aukštesnę dalį efektyvumas buvo mažesnis, nes augalų regeneracija buvo didelė, o kontrolės efektyvumas žymiai sumažėjo. Vienamečiai augalai keturių lapų augimo tarpsniu buvo jautrūs uždengimui plastikine plėvele. Jaunų piktžolių augalų uždengimas 30 dienų užtikrino pakankamai efektyvią kontrolę. Sosnovskio barščių terminė kontrolė (kai garų temperatūra buvo ≥95° C) buvo efektyviausia nuo skilčialapių iki 4 lapelių tarpsnio.
Dviejų necheminių metodų taikymas užtikrintų efektyvią vienamečių ir daugiamečių Sosnovskio barščių kontrolę.

Reikšminiai žodžiai: *Heracleum sosnowskyi*, invazinės piktžolės, mechaninė kontrolė, pjovimas, uždengimas, terminė kontrolė.