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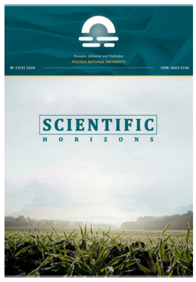

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Control of *Heracleum Sosnowskyi* Plant Numbers in Agricultural and Forestry Phytocenoses of Ukraine

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Abstract. As of today, *Heracleum Sosnowskyi* have expanded from transformed habitats and small areas into natural conditions, where they occupy stable positions and is characterised by high phytocenotic activity, often being dominant or co-dominant. Considering that there are no clearly developed methods of control of this invasive species, there still is an urgent need to develop the methods of control of both annual and perennial plants under conditions of Ukraine. The aim of the study was to determine the effectiveness of different methods of control of *Heracleum Sosnowskyi*. A field experiment was carried out during 2015-2020 on typical medium loam black soil. Four experiments were conducted: 1 – mechanical measures; 2 – screening; 3 – hot steam; 4 – use of herbicides. A randomised experimental design with four repetitions was used. It was found that an effective approach is the removal of the weeds with the root to a depth of at least 10-15 cm. Complete shading of the plants to the stage of four leaves within 30 days ensured their complete disappearance. The rate of *Heracleum Sosnowskyi plants* mortality by hot steam ranged from 100% (cotyledon stage) to 85% (6 leaves stage). The most sensitive to herbicides were the shoots in the cotyledon stage, from 97.3% to 100%. The most susceptible to herbicides in the phase of cotyledon was from 97.3% to 100%. To the phase of 6 leaves sensitivity decreased from 43.2 to 60.7%. The most effective herbicides were: TaskExtra 66.5 WG (rimsulfuron – 23 $g \cdot kg^{-1}$, nicosulfuron – 92 $g \cdot kg^{-1}$, dicamba – 550 $g \cdot kg^{-1}$) + Trend-90 at a consumtpion rate of 385 $g \cdot ha^{-1}$ + 0.2 $l \cdot ha^{-1}$ and MaisTer Power OD (foramsulfuron, 31.5 $g \cdot l^{-1}$ + iodosulfuron, 1.0 $g \cdot l^{-1}$ + tincarbazone-methyl, 10 $g \cdot l^{-1}$ + cyprosulfamide (antidote), 15 $g \cdot l^{-1}$) at a consumption rate of 1.5 $l \cdot ha^{-1}$). *Heracleum Sosnowskyi* the following herbicides proved to be efficient: Elumis 105 OD, MD (mesotrion 75 $g \cdot l^{-1}$, nikosulfuron, 30 $g \cdot l^{-1}$) at a consumption rate of 2.0 $l \cdot ha^{-1}$ and the following tank compositions: Elumis 105 OD, MD + Roundup Max v.r. (glyphosate potassium salt, 551 $g \cdot l^{-1}$) at a consumption rate of 2.0+6.0 $l \cdot ha^{-1}$. In further study of this issue, it is advised to increase the efficiency of controlling the number of *Heracleum Sosnowskyi* plants and reducing the chemical effect on the environment

Keywords: weeds, mechanical measures, screening, hot steam, herbicides

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INTRODUCTION

Heracleum Sosnowskyi Mandenova is significantly widespread in Ukraine. It is dangerous so it must be controlled. Since these plants are characterised by high biological productivity, competitiveness and vitality, they form a seed bank, that can grow under natural conditions during up to 5 years of conservation, it is difficult to effectively control their presence in residential areas and on agricultural land [1; 2].

Heracleum Sosnowskyi occupies a specific place among the weeds in the crops and the environment in general. The species, being at one time a promising fodder crop, has turned into an aggressive invasive and adventitious object, which poses a threat both for natural phytocoenoses and humans. The genus *Heracleum* L. belongs to the botanical family *Apiaceae*. The family includes some 300 genera and 3,990 species spread throughout the world. Central Asia and the Caucasus are considered to be the centre of the species diversity of the family [1]. The renowned Swedish taxonomist Carl Linnaeus described the genus *Heracleum* L. in 1735, which the Roman botanist Pliny named after the hero of Greek mythology Heracles, for its ability to rapidly increase its vegetative mass, large size, and its very stout appearance. The genus *Heracleum* L. is widely distributed in the world flora and includes 69 species, growing mainly in the temperate climatic zone of Eurasia [2; 3].

In Eurasia, the north border of the range of the genus stretches from the Scandinavian Peninsula to Kamchatka, and in North America from Alaska to Labrador and Newfoundland, the southern – covers North Africa, West and North Asia, in West America stretching from California and eastern Mexico to North Carolina. There are several major centres: East Asia, the mountainous regions of southern Europe and the Caucasus. Accordingly, the active expansion of giant *Heracleum Sosnowskyi* as an invasive species started approximately in the mid-1980s, almost simultaneously in different parts of Ukraine as well as in Europe, Russia and the Baltic states. *Heracleum Sosnowskyi* as an invasive species is also present in Germany, Hungary, Denmark and Poland [4; 5].

After successful acclimatisation, these plants due to their extremely high reproductive capacity (the main mass of *Heracleum Sosnowskyi* seeds crumbles right near the mother plant (up to 75,000-80,000 seeds per 1 plant) and are spread by wind, water currents, road and rail transport over long distances); their adaptability to habitat conditions is widespread [6]. At the beginning of its expansion, *Heracleum Sosnowskyi* was detected only in heavily anthropic disturbed ecotopes – along the roadsides, on the outskirts of settlements, in waste grounds, trash, near farms, in pits. At the second stage, they considerably increase the number and area of population and growth, some of them merge into large, solid groups. At the third stage, *Heracleum Sosnowskyi* plants successfully expand into natural ecotopes, croplands, and forests [7-10].

In the Baltic States since the 1980s, *Heracleum Sosnowskyi* has been considered a malignant and dangerous weed. In 1986 in Latvia and 1987 in Estonia, it was declared an aggressive weed, primarily due to the negative impact on the flavour of the meat and milk of the animals that ate it and partly because of health risks for humans and animals [11; 12]. In Belarus, according to recent data, every year the number of *Heracleum Sosnowskyi* growth increases by 30%, and the area of existing populations – by 20-25%. Analysis of the distribution of *Heracleum Sosnowskyi* growth areas by land categories showed that more than a half (49%) of populations of this species is centred on the lands of industry, transport, communications, energy, defence and other purposes, and primarily – on the roads. A significant proportion of the populations were found on lands of agricultural and farming purposes (23%), and lands of settlements, gardening associations, dacha cooperatives (26%) [13].

In Ukraine, *Heracleum Sosnowskyi* gradually invades new territories. It grows particularly fast in unkempt fields and other places with disturbed natural vegetation. Due to its large size, fast accumulation of biomass, and a high degree of plasticity, *Heracleum Sosnowskyi* is able in a short time to reduce the size of populations of a large number of local plants species, especially those growing in meadows and near-river areas, until they are completely displaced [14].

The purpose of this study was to investigate the control methods for both annual and perennial *Heracleum Sosnowskyi* plants within the Ukrainian environment.

LITERATURE REVIEW

According to the researchers, only 15-20 species of mostly weed-ruderal plants can survive in the synusia with *Heracleum Sosnowskyi*. From the structure of flood plain phytocenoses, this species pushes back the species of fodder and medicinal plants. As a consequence, there is a fall-out from the grass of rhizomatous plants with the replacement for *Heracleum Sosnowskyi* with a rod root system, which is not capable of forming a dense turf and holding the soil layer, leading to soil erosion [14; 15]. The life cycle of *Heracleum Sosnowskyi* plants can proceed in two variants: in the first one the plant develops as a biennial plant: in the first year it forms a large, ramified, and strong root system with a rosette of leaves, and in the next year – a sprout with inflorescences, that produce a significant amount of seed. In another variant, the species develop as a biennial plant and can blossom and bear fruit at the age of 3-7 years. The *Heracleum Sosnowskyi* is a cold-resistant plant and can live at – 4-7°C during its first year of life; from the second year onwards it can bear up to -25°C and even to -45°C when under the layer of snow. At the same time, the plants are light-demanding, poorly tolerant of shade and cover crops, and require moist soil [16; 17].

Human activity contributes to the spread of giant *Heracleum Sosnowskyi* plants: they often grow in roadside ditches and on roadside verges and other ecotopes of a ruderal character. *Heracleum Sosnowskyi* from transformed habitats move into natural, where they occupy a rather stable position and are characterised by high phytocoenotic activity, often acting as a dominant or co-dominant species. It is known that *Heracleum Sosnowskyi* increases the area occupied by its plants by 10% per year, but there is also information about its more intensive growth [18; 19]. Control of invasive *Heracleum Sosnowskyi* species requires the use of a wide variety of techniques. Phytosanitary control of roads and railways, settlements, green areas, roadside and field protective plantations needs to be strengthened. In order to choose optimal control methods it is necessary to consider environmental and coenotic needs of such species and peculiarities of agricultural activities in the region [20].

Mowing is one of the mechanical methods of controlling *Heracleum Sosnowskyi*. If to mow weed after seeds are created, it is not possible to prevent fresh seed from entering the soil. After pollination and fertilisation, the seedlings will be fully emerged after 10-12 days and will be able to fully develop into new full-grown plants. The efficient method is the cutting of flowers during the period of budding and the beginning of flowering and burning of plants during the period of seed development. It is effective to cut plants of any age to a depth of at least 10-15 cm from the soil surface, resulting in their complete death. However, this can be done in small areas. In addition, such an operation is potentially dangerous for staff, as it is easy to get juice and strong dermatoses on different parts of the body [21-24].

It is difficult to control the number of *Heracleum Sosnowskyi* due to the specifics of their biology, the potential risk posed by the plants themselves, the high level of plant productivity and the formation of a seed bank. Therefore, the chemical area is one of the tensions of control. Among systemic herbicides, specialists recommend using a product based on such active substances as glyphosate, sulphometuron-methyl and other sulphonylureas, imazapyr, or their tank compositions. The optimum phases of the treatment are from the beginning of the growing season in spring to the beginning of flowering. Herbicide application during the later stages of organogenesis is less effective [25; 26].

According to the data of both European and Ukrainian studies, the fastest results are obtained by the use of the active substance gliphosate (N-(phosphonomethyl)-glucine, $C_3H_8NO_5P$) in the form of ammonium, isopropylamine and calamine salt [18; 27]. Up to date, in Ukraine, chemical methods of *Heracleum Sosnowskyi* control have not been investigated sufficiently. Due to the latest data [18], the control of *Heracleum Sosnowskyi* plants use Roundup with the rate of consumption – 6.0 $l{\cdot}ha^{-1}$, or its analogues 6-8 $l{\cdot}ha^{-1}$ for the formation of vegetation height of 30-50 cm (the end of April – the first half of May). The available method is to mow the plants twice a year during the period of the flowering of the main (central) and repeatedly during the regeneration of the weed plants.

The heating effect of *Heracleum Sosnowskyi* plants (thermal method) is promising for agricultural areas where the use of herbicides is limited. Traditionally, plants are heated by a flare of fire or hot gases – products of the combustion of natural gas or petroleum products. High temperatures lead to denaturation of protein-enzymes and loss of their catalytic properties. As a result of this disorganisation of metabolic processes, the plants subsequently die [28-30].

MATERIALS AND METHODS

The research was carried out during 2015-2020 at the Herbology Department of the Institute of Bioenergy Crops and Sugar Beet of the NAAS (IBCBSBN) and the Bila Tserkva Experiment Breeding Station (BCEBS), located in the Central Forest Steppe of Ukraine, in the unstable hydration zone. Climate is temperate continental. Station area is located on the Prydniprovsk plateau of the Right Bank Highland. Relief terrain is flat. Forest is the main soil-forming agent. The depth of forest cover varies from 4 to 18 m. The prevailing soil is of the black soil type, surface, medium depth low-humus and different degrees of leaching, with a pronounced natural structure and good provisioning with nutrition elements. The soil of the investigated field is a typical leached black soil, of a medium loam mechanical composition, with humus horizon depth from 100 to 120 cm and humus part in the arable layer (0-30 cm) – 3.9%, which is characteristic for low humus black soil. It is also characterised by the following agrochemical indicators: the depth of the humus horizon – 50-60 cm, Ca and Mg carbonates occur at a depth of 50-65 cm. Hydrolytic acidity is 1.5-1.8 mg-eq·100 g^{-1} of soil. The amount of alkaline-hydrolysed nitrogen (according to Kornfield) is from 120 to 140 $mg{\cdot}kg^{-1}$, nitrate is 14.2-19.6 $mg{\cdot}kg^{-1}$; mobile phosphorus and exchangeable potassium (according to Chirikov) are from 180 to 240 and from 90 to 120 $mg{\cdot}kg^{-1}$ of soil. The acidity of the soil is neutral or close to neutral.

The main source of soil humidity is rainfall. Precipitation is variable throughout the year, most of it occurring during the warm period, especially in the middle of the summer (July) in the form of rain. In some years there is a period without rain in summer, which negatively affects the growth and development of crops. According to the Bila Tserkva meteorological station sum of effective temperatures (the sum of temperatures above 10°C during the growing season) is from 2,500 to 2,800°C, the amount of precipitation per year is 521 mm. The average air temperature is +7.4°C (a summary of the results of the last 25 years). In the years of research, weather conditions showed some deviations from the average perennial indicators, but in general, they were favourable for the growth and development of most species of crops, weeds and *Heracleum Sosnowskyi*.

The evaluation of the efficiency of different control methods *Heracleum Sosnowskyi* plants required a field study:

1. Mechanical influences on weed plants. The research included planting the seeds of *Heracleum Sosnowskyi* and their vegetation during one year. The following year, in the spring, experiments were carried out on the plots. At each site, 20 *Heracleum Sosnowskyi* plants were selected. The experiment was set in 4-time repetition. That is, 80 plants of weeds were used in each variant. The experiment plan included the following options: 1. Control. Plants grow without mechanical damage. 2. Cut into the ground at a depth of 5 cm. 3. Cut into the ground at a depth of 10 cm. 4. Cut off on the ground surface. 5. Cut off at a height of 5 cm above the ground. 6. Cut off at a height of 10 cm above the ground. 7. Cut off at a height of 15 cm above the ground. Mechanical damage to *Heracleum Sosnowskyi* plants is done when reaching the shoot height of 20 cm.

2. Control of Heracleum Sosnowskyi plants by the method of screening (monitoring of energy nutrition). *Heracleum Sosnowskyi* plants of the first (grown from seed) and the second year of growing were used for field experiments. The plot was planted with 20 plants in four repetitions. Accordingly, each variant had 80 *Heracleum Sosnowskyi* plants. The first plant cut was carried out during the formation of 20 cm high shoots. Experiment plan for plants of the first year of growing included: 1) shading during the phase of formation of 2 leaves for a period of 15 days; 2) cutting during the phase of 2 leaves + shading 15 days; 3) in the phase of the formation of 6 leaves + shading 15 days; 4) in the phase of 6 leaves + shading 30 days. For perennial plants: 1) cutting and shading during 15 days; 2) during 30 days; 3) during 45 days; 4) during 60 days; 5) during 30 days + second shading for 30 days.

3. Control of Heracleum Sosnowskyi plants by the heating method. The research was field-based. The area of the seeding plot is 3.0 m^2, the experimental plot is 2.0 m^2. The experiment is carried out 7 times. Plots location is regular. A portable steam generator was used to heat the *Heracleum Sosnowskyi* plants during their vegetation. The plants were heated with hot steam using a non-contact laser thermometer. To obtain plants with different phases of their development during the hot steam treatment, spring planting was carried out at an interval of 5 days. *Heracleum Sosnowskyi* plants were subjected to hot water vapour treatment during the following growth phases: 1. fruiting, 2. 2 leaves, 3. 4 leaves, 5. 6 leaves, 6. 8 leaves. The estimation of the efficiency level of hot steam heating of *Heracleum Sosnowskyi* plants to different temperatures was carried out according to the scheme: 1. Control – without induced heat stress of the plants. 2. Induced heat stress with a steam temperature of 800°C. 3. Heat-stress with steam at 850°C. 4. Heat stress with a steam temperature of 900°C. 5. Heat stress by steam at 950°C. 6. Thermal stress with steam at a temperature of 1,000°C. On each m^2 of the experimental plot, the density of 50 *Heracleum Sosnowskyi* plants was formed after the emergence of shoots. Accordingly, 700 plants were used for each variant of the study. Plants were always treated with hot steam in the experiments on all variants and repetitions on the same day. The efficiency level of hot steam was evaluated 7 days after the treatment.

4. Control of Heracleum Sosnowskyi plants using chemical protection agents. The size of the tested plots was 25 m². The experiment was carried out on a 4-times repeated basis. The agents were applied by a special laboratory gas sprayer on wheels with a reducer, rod, and a constant working pressure of 2.1 atm. The working fluid consumption rate was from 200 to 210 l·ha^{-1}. The screening was carried out at a temperature of 18ºC, and in sunny weather with a wind speed of up to 4 m·sec^{-1}. The working liquid was prepared without any intermediary before applying. In the process of changing herbicides, the applicator was necessarily washed with water, a part of the water was passed through a rod and sprayers. The evaluation of the herbicidal effect on *Heracleum Sosnowskyi* plants was carried out during the following growth phases of the weed plants: cotyledon, 2 leaves, 4 leaves, 6 leaves, 8 leaves.

<u>Experiment plan with annual *Heracleum Sosnowskyi* plants:</u>

1. Control, plots with no use of herbicides;
2. Betanal Max Pro 209 OD (phenmedipham 60 g·l^{-1} + desmedipham 47 g·l^{-1} + ethofumesate, 75 g·l^{-1} + lenacil (activator) 27 g·l^{-1}) at a cost of 1.0 l·ha^{-1};
3. Gezagard 500 FW (promethrin 500 g·l^{-1}) at an expanse rate of 3.0 l·ha^{-1};
4. Granstar Gold 75 (tribenuron-methyl 562.5 g·kg^{-1}, tifensulphuron-methyl 187.5 g·kg^{-1}) at an expanse rate of 35 g·ha^{-1};
5. Esterone 600 EC (905 g·l^{-1} 2-ethylhexyl ether; 2.4-dichlorophenoxyacetic acid, in acid equivalent 600 g·l^{-1}), at a rate of 0.8 l·ha^{-1};
6. Tasc Ekstra 66.5 WG (rimsulfuron 23 g·kg^{-1}, nicosulfuron 92 g·kg^{-1}, dicamba 550 g·kg^{-1}) + Trend-90 at a rate of 385 g·ha^{-1} + 0.2 l·ha^{-1};
7. MaisTer Power OD (foramsulfuron 31.5 g·l^{-1} + iodosulfuron 1.0 g·l^{-1} + thiencarbazone-methyl 10 g·l^{-1} + cyprosulfamide (antidote), 15 g·l^{-1}) at a rate of 1.5 l·ha^{-1}.

<u>Plan of experiment into the perennial *Heracleum Sosnowskyi* plants:</u>

1. Control, plots without the use of herbicides.
2. Roundup Max WG (Glifosatu potassium salt 551 g·l^{-1}) at a consumption rate of 6.0 l·ha^{-1}.
3. Banvel 4S, 480 SL (dicamba 480 g·l^{-1}) at a consumption rate of 0.8 l·ha^{-1}.
4. Elumis 105 OD (mesotrion 75 g·l^{-1}, nikosulfuron 30 g·l^{-1}) at a rate of 2.0 l·ha^{-1}.
5. Banvel 4S, 480 SL at a consumption rate of 0.8 l·ha^{-1} + Roundup Max WG at a consumption rate of 6.0 l·ha^{-1}.
6. Elumis 105 OD at a consumption rate of 2.0 l·ha^{-1} + Roundup Max WG at a consumption rate of 6.0 l·ha^{-1}.

RESULTS AND DISCUSSION

Mechanical impact on Heracleum Sosnowskyi plants

The study was carried out with *Heracleum Sosnowskyi* plants of the second year of the growing season. In spring, after the beginning of active growing of weed plants which successfully survived winter and reached a height of 20 cm, they were cut mechanically according to the scheme given in the methodology. The results of this mechanical influence on *Heracleum Sosnowskyi* plants are presented in Table 1.

***Table 1**. Regeneration capacity of Heracleum Sosnowskyi plants after mechanical damage, 2013-2015*

No.	Schematic diagram of the design	Shoots growth, cm	Raw plant mass, g·m^2	Leaf area, cm^2·plant^{-1}
1	Control (no cuts)	273	4,241	15,734
2	5 cm lower than the soil surface	74	327	811
3	10 cm lower than the soil surface	-	-	-
4	0 cm from the soil surface	139	412	913
5	5 cm above the surface of the soil	147	421	927
6	10 cm above the surface of the soil	153	425	1,010
7	15 cm above the surface of the soil	157	432	1,017
	$LSD_{0.05}$	9.3	32.4	68.3

The following growth of the weed plants was successful in most of the experiment variants. In the control plots, variant 1, where no cuts were carried out, the plants underwent successive stages of organogenesis. At the generative stage of organogenesis (flowering) the height of *Heracleum Sosnowskyi* plants reached an average of 2.73 m with the leaves area of 15,734 cm^2·plant^{-1}. The mechanical cuts of the plants on the soil level required the renewal of the lost above-ground parts and the re-forming of the stems and leaves. The new stems heights averaged 1.39 metres, or 49.1% less than the control variant plants (var. 1). In addition to a decrease in the ability to form the height of the shoots, the possibility of forming the above-ground mass in the previously cut plants also decreased. On average it was 412 g·(m^2)$^{-1}$ or a 90.3% decrease compared to plants of variant 1. The leaf area of *Heracleum Sosnowskyi* at the time of flowering was 913 cm^2 per plant or 94.2% less than in the plants of variant 1.

There was a tendency to a decrease in the height of the shoots, which growth was less pronounced, of weed plants with an increase in the height of their mechanical cut (5, 10, 15 cm from the soil surface). Part of the above-soil mass of such plants, and primarily, their leafy apparatus, was preserved and continued to function successfully. The plants did not need to completely renew it. As a result, the height of the plants' shoots was between 147 cm and 157 cm after growth. The total volume of formation of a raw mass of above-soil parts of *Heracleum Sosnowskyi* after cut and subsequent growth also decreased, but the value of the decrease was in the range of 89.8-90.1% of the total volume of a raw mass of plants of the weed plants of variant 1. A similar trend was noted in the value of the formation of the leaves area of weed plants. The cutting of the above-ground parts of *Heracleum Sosnowskyi* plants significantly decreased their biological productivity, but they successfully continued their growth and passed the next stages of their organogenesis.

The mechanic cutting of the weed plants below the soil surface was based on the morphological peculiarities of the upper buds on the underground parts of the plants in the soil (cryptophytes). Mechanical cutting of the plants at a depth of 5 cm from the surface of the soil significantly reduced their regenerative capacity to renew lost above-ground parts and buds. The most developed apical buds in the plants were lost as a result of such mechanical damage. After the application of such mechanical undercuts, only those adventitious buds which remained undamaged on the underground parts of *Heracleum Sosnowskyi* plants ensured regrowth. By the end of the growth period, the new bud of weed plants had an average height of 74 cm or a decrease of 72.9% compared to the plants of variant 1 was 72.9%. The plants formed an average of 327 g·(m^2)$^{-1}$ mass of above-ground parts or the decrease compared to the level of plants on the control plots was 92.3%.

The use of such a technique significantly reduced the biological potential of *Heracleum Sosnowskyi* plants, but showed a significant disadvantage: it did not ensure the complete elimination of the weed plants. During the following growth periods, the plants were able to gradually regain their high competitiveness. The research scheme included (var. 3) cutting of the weed plants 10 cm below the soil surface. This depth of mechanical damage involved damaging almost all the buds of the growth regeneration that plants form at the top of the overgrown root. This mechanical approach deprived the weed plant of its ability to regenerate. The underground parts, which had a well-developed root system and a reserve of plastic substances, lost their connection with the buds of the growth recovery as the result. The upper part buds were not linked with plastic substances and the root system. Consequently, both parts of the plants have since been non-viable and have gradually died out. Similar results were obtained by researchers in Lithuania [27], Poland [24], and Russia [22].

Control of Heracleum Sosnowskyi plants with the method of screening (monitoring of energy consumption)

For successful photosynthetic processes, the essential prerequisite for green plants is the availability of access to the flow of light energy, first and foremost PAR energy (photosynthetically active radiation of the light wavelengths between 380 nm and 710 nm), which is supplied to their above-ground parts. To achieve attenuation or complete deprivation of the energy (light) life of weed plants, including *Heracleum Sosnowskyi*, thus blocking the photosynthesis processes in them is the easiest way to screen with the optically non-isolated screen [16; 17]. The study evaluated the reaction of *Heracleum Sosnowskyi* plants of the first year growth (from seed) on the duration of the period of their shading and their ability to bear mechanical damage.

On the plots of variant 1, the young weed plants grew without mechanical damage or screening. In the plots of variant 1, the young plants grew without mechanical damage or scarring. On the plots of var. 2 after the formation of 2 true leaves, the plants were covered with black film for a period of 15 days. After the shading period was over, the plants were in severe energy distress, but they gradually resumed photosynthetic processes and continued their successful growth. On the plots of variant 3 *Heracleum Sosnowskyi* plants, after the formation of 2 leaves, were cut and covered with black film for 15 days. The plants were 100% dead before the shading period was over.

The plants from the plots of var. 4 successfully grew after the emergence of shoots. They were cut during the formation phase of 6 leaves and then covered with black film for 15 days. After the shading period, 6.2 units of plants or 7.7% continued growing. The main part of the *Heracleum Sosnowskyi* died out. On the plots of variant 5 bushes were cut in the phase of 6 leaves and covered with black film for 30 days. By the end of the shading period, all the test plants were dead. The ability of *Heracleum Sosnowskyi* plants of the first year of growth to survive primarily depended on the presence and size of plastic substances reserves and the duration of the shading period.

In order to evaluate the possibilities of control of perennial *Heracleum Sosnowskyi* plants (of the second year of growth) through screening, field studies were carried out. On the plot, 20 units of plants were grown in four replications. Accordingly, each variant was represented by 80 *Heracleum Sosnowskyi plants*. The change of conditions of energy (light) supply to the plants at the initial growth period (from the appearance of buds on the roots) manifested unequal influence on the course of the following stages of their organogenesis. The most important was the change in the intensity of the PAR energy flux, which reached the surface of leaves of young plants and the possibility of its absorption by their above-ground parts. In *Heracleum Sosnowskyi* plants of the second-year growth, at the initial stage of ontogenesis under conditions of almost complete absence of (light) provision, the energy distress occurred, which manifested itself in loss of the ability of plants to form new organic substances.

The reserves of plastic substances of the previous growth period in the underground (perennial) parts of the plants are used for the formation of repeated annual shoots and leaves since the previous ones were lost as a result of their first cut. According to the growth conditions of Variant 2, where *Heracleum Sosnowskyi* plants were cut above the soil surface and then shaded for the next 15 days, the formation of raw mass amounted to 4,702 g per m^2 during the following growth period. The plants tolerated the increased duration of the shading period up to 30, 45 and 60 days, but in such conditions of photosynthetic processes absence, the plants decreased their ability to produce above-surface weight during the next growth period by 8.5, 20.2, and 63.3% (Table 2).

***Table 2**. The capacity of Heracleum Sosnowskyi plants to form above-surface weight, (g per 1 m^2) after cutting and the period of screening, 2015-2020*

Experiment variants	Period of shading, days			
	15	30	45	60
1	Control without cutting (all plants grow successfully)			
2	4,702	4,333	3,910	2,880
3	4,705	4,544	1,638	793
4	4,755	4,386	1,480	–
5	4,597	4,491	1,585	–
$LSD_{0.05}$	126.2			

Variants 6 and 7 of the research scheme included two subsequent cuttings of *Heracleum Sosnowskyi* plants (the second growth of above-surface parts after 30 days of shading after the first) and the following shading for another 30 days (variant 7 for 45 days) resulted in partial (variant 6) mortality (67.5% or 54 plants out of 80 in this variant) The weed plants bourbon from variant 7, where the duration of re-shading after the second cutting was 45 days, died completely.

Identification of the sensitivity of Heracleum Sosnowskyi plants to water vapour during different phases of their development

According to a range of scholars herbologists [28-30], the heating of juvenile *Heracleum Sosnowskyi* plants may contribute to significant control of their numbers. Investigation of the reaction of weed plants to induced thermal distress was carried out using a portable steam generator. *Heracleum Sosnowskyi* plants were treated with 100°C steam at the nozzle outlet at a distance of 10-12 cm. The velocity of the steam flow is 5 m·sec^{-1}. The power of the flow of steam on the emerged plants lasted from 0.5 to 0.8 sec. The investigations were model field-based.

The results of the research are summarised in Figure 1. *Heracleum Sosnowskyi* plants' treatment with hot steam resulted in complete disorganisation of metabolism processes in cells of young plant tissues. The thickness of tissue descents in the phase of cotyledon in the above-surface parts of plants is insignificant and they were quickly heated to a temperature close to 100°C. The transfer of heat from the plant surface into the soil was well handled by the tissues themselves since they are very watered during this period of organogenesis. Traditionally, the water part in cells of *Heracleum Sosnowskyi* plants tissues is from 80 to 94% of their total mass.

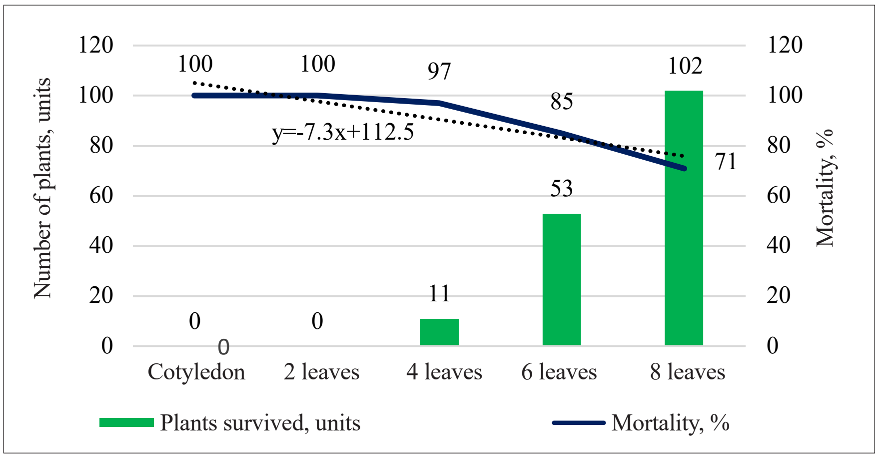

***Figure 1**. Changes in phase sensitivity of Heracleum Sosnowskyi plants to water vapour heating*

The weed growth phases build-up (formation of 2 true leaves) increased the area of their contact with the flow of hot steam, but the mass of the plants grew steadily and their ability to resist the rapid heating of tissues in the depths increased. The *Heracleum Sosnowskyi* plants died completely. At the phase of formation of 4 leaves in the different species of weed plants, their sensitivity to the influence of high temperatures compared to the previous phases of growth tended to decrease. *Heracleum Sosnowskyi plants*, which were used in the study in this phase of growth, died out by 97%, or 339 units in the study variant. However, 11 plants or 3% of the total number in the variant survived and continued to grow.

The hot steam treatment of the emerged *Heracleum Sosnowskyi* plants during the formation of 6 leaves showed a significant increase in their resistance to heating. This effect can be explained by the accumulation by the above-surface parts of young *Heracleum Sosnowskyi* plants of a greater mass, which requires a greater amount of heat energy to heat as well as the complicated process of heating the plant tissues in their midst, especially the heating of meristem tissues at the growth points both apical and collateral on the stems. Consequently, the rate of mortality of the *Heracleum Sosnowskyi* plants was lower than that of the previous plants. The plants were dying by 65% during the phase of formation of 6 leaves.

The hot steam treatment of *Heracleum Sosnowskyi* plants was less effective in the phase of formation of 8 leaves compared with the previous stages of their growth. The weed plants died by 80% as a result of temperature stress by means of hot steam, i.e., 62 plants out of 350 in the study variant continued to grow.

Identification of the sensitivity of Heracleum Sosnowskyi plants to water vapour at different temperatures

In the process of research of peculiarities of sensitivity of *Heracleum Sosnowskyi* plants to hot steam, a certain specificity of indicators of plants sensitivity and phases of development on the level of their mortality from heat stress was determined. However, the level of plant vulnerability to heat is influenced by the parameters of hot vapour flow temperature, i.e., the level of heating of the emerged plants themselves and their ability to survive in the next period. The temperature of hot steam flow that was in contact with the plants in the experiments had different temperatures: from 80 to 100°C with intervals between variants of 5°C. The growth phase of *Heracleum Sosnowskyi* plants in the studies was the same – 4 true leaves. The temperature of plants heating with hot steam was controlled by a special non-contact laser thermometer.

The treatment of the above-surface parts of plants by a stream of water vapour at 80°C had a significant effect on their ability to continue their growth. The *Heracleum Sosnowskyi* plants which were heated to a temperature of 80°C received thermal stress which resulted in the mortality of 53% of the total number of plants that were in the variant. At the same time, 164 plants or 47% of the total number survived (Fig. 2). The rise in the temperature of *Heracleum Sosnowskyi* plants by water vapour to 85°C provided them with more severe thermal stress and accordingly tended to increase the number of plants which could not counteract such negative influences. The result was that the mortality rate was 64%, or an average of 126 plants survived out of 350 emerged ones in the variant. Application of higher heat up to 90°C for *Heracleum Sosnowskyi* plants increased the mortality rate of plants due to thermal stress. As a result of heat treatment, 78% of the plants that were used in the study variant died.

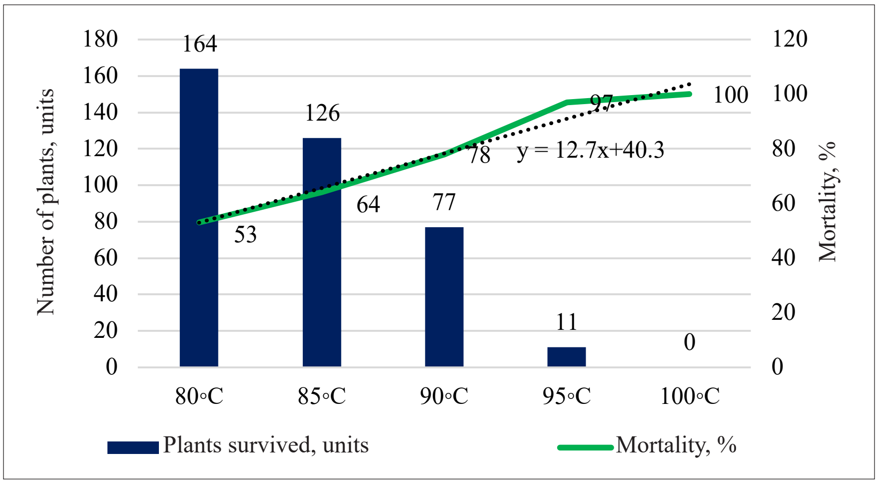

***Figure 2**. Sensitivity of Heracleum Sosnowskyi plants during the 4 leaves phase to water vapour heating*

Heating the *Heracleum Sosnowskyi* plants to 95°C resulted in 97% mortality of all in the variant. Only 11 plants out of the 350 used in the study survived. Thus, the level of efficiency in the protective effect of hot steam flow on the emerged *Heracleum Sosnowskyi* plants was at a level that can provide a highly effective herbicide. The increase of *Heracleum Sosnowskyi* plants (phase of forming of 4 leaves) heating temperature up to 100°C led to complete death, that is 100% of weed plants stopped their growth.

Summarising the results of the efficiency of water vapour effect on the emerged *Heracleum Sosnowskyi* plants with the temperature of plant heating to 80°C it can be stated that the applied thermal stresses can influence the young plants significantly. Increasing the heating temperature of the emerged *Heracleum Sosnowskyi* plants to 90°C resulted in greater heat stress in the plants. As a result some of them gradually died out, the other part after a long period of depression (from 7 to 20 days) survived and continued their growth. An increase in water vapour temperature and heating level of the emerged *Heracleum Sosnowskyi* plants, according to the research plan requirements, up to 95°C, ensured an increase of thermal stress in young plants and correspondingly high level of their next death.

The general level of reduction in a number of the emerged *Heracleum Sosnowskyi* plants as a result of heating of plants during the phase of formation of 4 leaves at 95°C reached an average of 96.3%.

Effectiveness of herbicides on Heracleum Sosnowskyi plants

The study was carried out on *Heracleum Sosnowskyi* plants of the first year of growth, that emerged from seed. Herbicides were applied by means of application during different growth phases of the weed plants. The research showed that such agents as TaskExtra 66.5 WG (385 $g \cdot ha^{-1}$) and MaisTer Power OD (1.5 $l \cdot ha^{-1}$) can effectively control *Heracleum Sosnowskyi* plants during the cotyledon phase. The effectiveness of their action reaches – 100%. In the growth and development build-up phase of *Heracleum Sosnowskyi*, the efficiency of these agents decreased and reached accordingly in the phase of formation of 2 leaves – from 99.7% to 99.4%, in the phase of 4 leaves – from 85.7% to 84.2%, in the phase of 6 leaves – from 63.2% to 60.7%. The effect of the growth of phase resistance of plants to herbicides appeared. Other herbicides, which were used in the research plan, showed a lower rate of the efficiency level of control of emerged weed plants (Table 3).

***Table 3**. Level of efficiency of herbicides on Heracleum Sosnowskyi plants during the first growth period in different phases of their development, (% mortality) 2015-2020*

Herbicides and their consumption rates	Phases of development of *Heracleum Sosnowskyi* plants				
	cotyledon	2 leaves	4 leaves	6 leaves	8 leaves
Control, without the use of herbicides	0	0	0	0	0
Betanal Max Pro 209 OD – 1.0 l·ha^{-1}	97.3	85.4	62.1	43.2	23.3
Gezagard 500 FW s.c. – 3.0 l·ha^{-1}	80.1	73.2	61.1	38.4	21.4
Granstar Gold 75, w.g. – 35 g·ha^{-1}	87.3	79.4	61.3	39.7	22.6
Esteron 600 EC e.c. – 0.8 l·ha^{-1}	87.2	77.9	62.2	40.1	24.5
TaskExtra 66.5 WG + Trend – 385 g·ha^{-1} + 0.2 l·ha^{-1}	100	99.7	85.7	63.2	38.7
MaisTer Power OD, o.d. – 1.5 kg·ha^{-1}	100	99.4	84.2	60.7	43.2

Heracleum Sosnowskyi plants change their level of sensitivity to herbicides in the process of ontogenesis. While in the cotyledon phase the mortality rate of the emerged plants reached 100%, in the phase of 6 leaves the level of sensitivity decreased to an average of 40-60%. The treatment of the plants during the next phases of growth (8 leaves) was less effective. One of the prerequisites for successful control of *Heracleum Sosnowskyi* plants in crops is to carry out the immediate treatment when the plants are in the cotyledon phase of 2 leaves.

Effect of herbicides on Heracleum Sosnowskyi plants

It is more difficult to control the *Heracleum Sosnowskyi* plants of the second and subsequent years of growth with herbicides than those annual plants. To assess the level of efficiency of herbicides application on plants of the second year of growth after the beginning of regrowth and the formation of 3 true leaves, the field studies were carried out. Evaluation of the efficiency of various herbicidal tank combinations on *Heracleum Sosnowskyi* plants was carried out in 30 days after the treatment in accordance with the research plan showed the following results (Table 4).

***Table 4**. Effectiveness of various herbicides, (mortality, %) on Heracleum Sosnowskyi plants (2013-2015)*

No. var.	Herbicides and consumption rates, l·ha^{-1}	Effectiveness of herbicides, %	Weed plant mass, g·plant^{-1}	
			30 days after herbicide application	60 days after herbicide application
1	Control, without the use of herbicides	–	3,124	3,251
2	Roundup Max WG at a rate of 6.0 l·ha^{-1}	87.0	–	322
3	Banvel 4S, 480 SL at a rate of 0.8 l·ha^{-1}	54.0	2,731	3,010
4	Elumis 105 MD at a rate of 2.0 l·ha^{-1}	100	0	0
5	Banvel 4S s.c. at a rate of 0.8 l·ha^{-1} + Roundup Max WG at a rate of 6.0 l·ha^{-1}	100	0	0
6	Elumis 105MD at a rate of 2.0 l·ha^{-1} + Roundup WG at a rate of 6.0 l·ha^{-1}	100	0	0

The *Heracleum Sosnowskyi* plants successfully passed the stages of their ontogenesis and started flowering on the plots of the variant 1 (Control without herbicides). In the plots of var. 2 as a result of herbicide Roundup, a.s. (6.0 l·ha^{-1}) the above-surface part of the plants completely died out (100%). However, some of the plants still continued to grow and formed above-surface mass. The results of research carried out in Lithuania also indicate the low efficiency of different rates of glyphosate application, because after 4-6 months the plants emerged again. A mixture of gliphosate and triasulphuron was more effective [27].

On the plots of variant 3 the result of herbicide Banvel 4S 480 SL (0.8 l·ha^{-1}) the *Heracleum Sosnowskyi* plants had a downtrodden appearance, the leaves were twisted. However, the above-surface parts of the plants remained alive and continued their growth. In the plots of variant 4 as a result of herbicide Elumis 105 OD MD (2.0 l·ha^{-1}) was noted complete destruction of weed plants. On plots of variant 5 as a result of tank herbicidal compositions Banvel 4S 480 SL + Roundup WG at a rate consumption of 0.8+6.0 l·ha^{-1} *Heracleum Sosnowskyi* plants were completely dead. In the plots of Variant 6 as a result of exposure to herbicides Elumis 105 OD, MD + Roundup WG at a rate of 2.0+6.0 l·ha^{-1} the *Heracleum Sosnowskyi* plants both above- and below-surface parts died out completely (Table 4). Such tank herbicide compositions for control of perennial *Heracleum Sosnowskyi* plants are suitable for use on arable lands after harvesting of cultivated plants.

According to foreign researchers [24], the complete struggle against this weed is achieved by cutting the roots of plants up to 5 years old to the depth of 15 cm or by continuous (5 years) application of three times during the growth period with the use of a tank mixture of Gliphosate and Flazasulphuron. (1,260 g of glyphosate per 1 ha + 50 g of flazasulphuron on 1 ha). It is also noted that a high effect on *Heracleum Sosnowskyi* plants is caused by a mixture of Fluroxipyr + Metsulphuron-Methyl [27].

A prerequisite for successful control of annual *Heracleum Sosnowskyi* plants in crops is a regular test of crops and identification of species composition of weeds in cotyledon phase to detect in time the presence of such species of weeds and implement preventive measures.

CONCLUSIONS

1. Mechanical control methods. *Heracleum Sosnowskyi* plants are characterised by a high level of biological productivity and can easily regenerate the lost above-surface parts. The regeneration process only reduces the ability of plants to form above ground mass by 89.8-90.3%. The maintenance of the perennial plants is advisable to be carried out in the soil at a depth of more than 10 cm, which ensures the effective control of *Heracleum Sosnowskyi* and eliminates the effect of their subsequent regrew.

2. Screening techniques. Annual *Heracleum Sosnowskyi* plants are quite sensitive to their screening (total shading), especially in the early stages of organogenesis: from 2 to 4 leaves. Efficient shading of juvenile annual plants for more than 30 days ensured their death. Screening of *Heracleum Sosnowskyi* plants at the next stages of their organogenesis proved to be less effective. For a significant decrease in biologic productivity of annual weed plants before their death after their formation of 6-10 leaves the minimum period of shading should be at least 60 days. In perennial *Heracleum Sosnowskyi* plants, supplementing shading with two consecutive cuttings of the shaded above-ground parts accelerated depletion of their plastic substances and dying during 45-60 days of the next treatment.

3. Thermal control method. The sensitivity of *Heracleum Sosnowskyi* plants to hot steam decreases with growth build-up phases of plants. The level of mortality was from 100% (cotyledon phase) to 85% in the phase of the formation of the 6-leaf plant. The efficiency of thermal control of *Heracleum Sosnowskyi* plants (4 leaves) also depended on the indicators of heat-carrier – hot steam. At a hot steam temperature of 80°C, 53% of the weed plants died. An increase in steam temperature to 95°C led to the mortality of plants at 96.3%, which means that they did not concede the level of herbicides. The thermal method of *Heracleum Sosnowskyi* control is sufficiently effective and environmental-friendly. It can be successfully used for *Heracleum Sosnowskyi* control in rural areas where the use of herbicides is restricted.

4. Chemical control method. The sensitivity of weed plants to herbicides varied with the growth build-up phases of plants. *Heracleum Sosnowskyi* plants were the most sensitive to herbicides in the phase of cotyledon: the level of efficiency was from 97.3 to 100%. Up to the phase of 6 leaves, the sensitivity of the emerged weeds decreased from 43.2 to 60.7%. Among the agents, the highest level of efficiency on *Heracleum Sosnowskyi* plants was recorded in the plots with the use of herbicides Task Ekstra 66.5 WG + Trend-90 at a consumption rate of 385 $g \cdot ha^{-1}$ + 0.2 $l \cdot ha^{-1}$ and MaisTer Power OD at a rate of 1.5 $l \cdot ha^{-1}$. The study of the level of efficiency of herbicides effect on perennial *Heracleum Sosnowskyi* plants showed that the most powerful was the effect of herbicides Elumis 105 OD, at a rate of 2.0 $l \cdot ha^{-1}$ and a tank composition of Elumis 105 OD, MD + Roundup Max WG at a rate of 2.0+6.0 $l \cdot ha^{-1}$ and Banvel 4S s.c. at a rate of 0.8 $l \cdot ha^{-1}$ + Roundup Max WG at a rate of 6.0 $l \cdot ha^{-1}$.

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Контроль численності рослин *Heracleum Sosnowski* в сільськогосподарських і лісогосподарських фітоценозах України

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Анотація. На сьогодні борщівник Сосновського із трансформованих місцезростань чи невеликих осередків поширився у природні умови, де займає стабільні позиції й характеризується високою фітоценотичною активністю, часто виступає домінантом або співдомінантом. Враховуючи те, що немає чітко розроблених методів контролю рослин цього інвазійного виду, актуальним залишається розробка прийомів контролювання як однорічних, так і багаторічних його рослин в умовах України. Метою дослідження було визначення ефективності різних методів боротьби з рослинами *Heracleum Sosnowskyi*. Польовий експеримент проводився протягом 2015–2020 років на типовому середньосуглинковому чорноземі. Було створено чотири експерименти: 1 – механічні заходи; 2 – екранування; 3 – гаряча пара; 4 – застосування гербіцидів. Використовували рандомізований експериментальний план із чотирма повтореннями. Встановлено, що ефективним заходом є видалення бур'янів з корінням на глибину не менше 10–15 см. Повне затінення рослин до стадії чотирьох листків протягом 30 днів забезпечило їх повне зникнення. Відсоток вимирання H. sosnowskyi від гарячої пари коливався від 100 % (стадія сім'ядолі) до 85 % (стадія шести листків). Найбільш чутливі до гербіцидів сходи бур'янів у стадії сім'ядолей – від 97,3 до 100 %. Найбільш чутливі сходи бур›яну до дії гербіцидів у фазу сім›ядоль: відмирання від 97,3 до 100 %. До фази 6-ти листків чутливість знижувалась від 43,2 до 60,7 %. Найбільш ефективними були гербіциди: Таск екстра 66,5 в.г. (римсульфурон – 23 г·кг$^{-1}$, нікосульфурон – 92 г·кг$^{-1}$, дикамба – 550 г·кг$^{-1}$) + Тренд-90 у нормі втрати 385 г·га$^{-1}$ + 0,2 л·га$^{-1}$ та МайсТер Пауер ОД (форамсульфурон, 31,5 г·л$^{-1}$ + йодосульфурон, 1,0 г·л$^{-1}$ + тієнкарбазон-метил, 10 г·л$^{-1}$ + ципросульфамід (антидот), 15 г·л$^{-1}$) у нормі витрати 1,5 л·га$^{-1}$). На багаторічні рослин борщівника Сосновського ефективно діяли гербіциди: Елюміс 105 OD, МД (мезотріон, 75 г·л$^{-1}$, нікосульфурон, 30 г·л$^{-1}$) у нормі витрати 2,0 л·га$^{-1}$ та бакової композиції: Елюміс 105 OD, МД + Раундап Макс, в.р. (гліфосату калійна сіль, 551 г·л$^{-1}$) у нормі витрати 2,0+6,0 л·га$^{-1}$. У подальшому дослідження цієї проблеми доцільно проводити в напрямі підвищення ефективності заходів контролювання чисельності рослин борщівника Сосновського та зменшення при цьому хімічного пресу на довкілля

Ключові слова: бур'яни, механічні заходи, екранування, гаряча пара, гербіциди