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Influence of herbicides on the growth and development of the invasive species *Heracleum Sosnowskyi* Manden.

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Abstract. The aim of the study was to evaluate the effectiveness of different herbicide treatments in suppressing the growth, development, and regenerative capacity of the invasive species *Heracleum sosnowskyi* Manden. The study was carried out using four variants: control without herbicides, Slash KE (1.5 L/ha), Roundup Max RK (4.0 L/ha), and combined application of Elumis OD (2.0 L/ha) and Roundup Max RK (2.5 L/ha). To assess herbicide effects, plant morphometric parameters (height, stem diameter, leaf area), phenological stages (stem elongation, budding, flowering), and the number of regenerative shoots were recorded over a 30-day observation period. Results showed that control plants exhibited high growth rates, significant increases in morphometric parameters, and active generative activity, including the formation of regenerative shoots. Application of single herbicides led to partial suppression of growth and generative development, while regenerative shoots still formed, although in smaller quantities compared to the control. The most pronounced effect was observed under the combined application of Elumis OD (2.0 L/ha) and Roundup Max RK (2.5 L/ha). In this variant, plant height, stem diameter, and leaf area were reduced to minimal values, the generative cycle was almost completely blocked, and the number of regenerative shoots remained stable or decreased, indicating complete suppression of the regenerative mechanisms of *Heracleum sosnowskyi*. The practical significance of the results lies in the fact that combined herbicide treatment can be an effective method for controlling this invasive species in agroecosystems and semi-natural habitats, preventing its spread and reducing the negative impact on agricultural productivity

Keywords: chemical control; physiological response; morphometric analysis; phenological changes; weed management

INTRODUCTION

The invasion of alien plant species represents a major global ecological challenge, with far-reaching consequences for both the structure and functional integrity of natural and semi-natural ecosystems. These species can drastically alter plant community composition, leading to homogenisation of habitats and loss of native biodiversity. According to C. Fritsch *et al*. (2025), the expansion of invasive plants not only changes the species composition of phytocenoses but also disrupts trophic interactions, including herbivore-plant and predator-prey relationships, ultimately reducing the capacity of ecosystems to provide essential services such as nutrient cycling, pollination, and soil stabilisation. A. Rysiak *et al*. (2021) further emphasised that the combination of increasing anthropogenic pressure, such as land-use change, agricultural intensification, and urban

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expansion, together with ongoing climate change, creates favourable conditions for invasive species. These species often exhibit high phenotypic plasticity, rapid growth rates, and superior reproductive strategies, which confer significant competitive advantages over native plants and facilitate their rapid spread and stable establishment in previously uncolonised areas. Moreover, the ecological impact of invasions is not limited to plant communities; it cascades across multiple trophic levels, affecting microbial communities, invertebrates, and even higher vertebrates, thereby reshaping ecosystem functionality and resilience over both short and long temporal scales.

In Ukraine, the spread of invasive species has become particularly concerning, as highlighted by H. Korpita (2025), due to intensive landscape transformation driven by urbanisation, infrastructure development, and changes in agricultural practices. These anthropogenic changes lead to the reduction of traditionally cultivated areas and the fragmentation of habitats, while the destruction of natural barriers – such as hedgerows, forests, and riverine corridors – removes critical constraints that previously limited the expansion of alien plants. As a result, invasive species such as *Heracleum sosnowskyi* are able to rapidly colonise new territories, establish dense populations, and outcompete native flora, creating significant ecological and socio-economic challenges.

Among alien flora, *Heracleum sosnowskyi* Manden. is considered one of the most aggressive and ecologically destructive species. E. Grzędzicka (2022) highlighted its high ecological plasticity, rapid growth, and significant seed productivity, which enable the formation of dense monodominant stands that displace native species, reduce herbaceous biodiversity, and disrupt natural vegetation regeneration, while also posing socio-economic risks due to the phototoxic furanocoumarins in its aerial parts. Current control methods for *Heracleum sosnowskyi* include mechanical, agronomic, biological, and chemical approaches. A. Judžentienė *et al*. (2026) emphasised that simple mechanical mowing or digging often fails to achieve long-term suppression because the plant can actively regenerate from underground organs. Biological control, although promising, remains limited in practical application. Therefore, systemic herbicides are regarded as one of the most effective strategies for controlling this invasive species, especially in large or difficult-to-access areas.

As noted by E. Borska *et al*. (2025), the effectiveness of herbicides should not be evaluated solely by population reduction. Systemic chemical action triggers physiological disruptions, including inhibited growth, altered morphogenesis, and phenological shifts, ultimately reducing the plant's recovery capacity. A. Čerevková *et al*. (2024) stressed that a comprehensive, multi-level evaluation of plant responses is necessary for an objective assessment of chemical control efficacy. International studies also provide valuable insights. D.P. Barrett *et al*. (2021) demonstrated that herbicide treatments applied at early growth stages achieve the greatest effectiveness, while later stages are much less responsive to chemical control. L.S. Pile Knapp *et al*. (2023) further showed that research on *Heracleum sosnowskyi* extends beyond control efforts to exploring biomass utilisation and potential beneficial applications. Additionally, C.S. Rodriguez *et al*. (2024) and S. Kalisz *et al*. (2021) analysed invasion dynamics and practical management measures, including mechanical and chemical methods, emphasising the importance of integrated approaches that combine quantitative and qualitative evaluations of plant responses.

The scientific literature clearly demonstrates the active and multifaceted development of research devoted both to the spread dynamics of *Heracleum sosnowskyi* and to a deep evaluation of its significant ecological impact, as well as the search for the most effective control methods. Among these, chemical approaches, particularly herbicide treatments, consistently occupy a central role. At the same time, ongoing efforts to develop radically new approaches and expand existing invasion management models further emphasise the continuous and critical relevance of this topic for modern science. The aim of this study was to determine the effectiveness of systemic herbicides and their combinations in suppressing growth, generative development, and regenerative potential of *Heracleum sosnowskyi*.

MATERIALS AND METHODS

The study was conducted during 2020-2025 in natural phytocenoses of the Western Forest-Steppe of Ukraine. The objects of investigation were biennial and perennial plants of *Heracleum sosnowskyi*. Field observations were carried out on plots with relatively uniform vegetation density, ensuring the comparability of obtained results. Herbicide treatments were applied at the rosette stage and during the initial phases of intensive vegetative growth, which are considered the most sensitive to systemic herbicides. This timing of application allowed the evaluation of the maximum biological effect of the herbicides at the early stages of *H. sosnowskyi* development. The control treatment involved no herbicide application. The working solution was applied using a tractor-mounted sprayer with controlled pressure to ensure uniform coverage of the plants (Table 1).

Table 1. *Herbicides, application rates and active ingredients used in the experiment*

Variant	Herbicide	Application rate	Active ingredient
I	Control (without herbicide application)		
II	Slash	1.5 L/ha	5 g/L Halauxifen-methyl; 120 g/L clopyralid
III	Elumis + Roundup Max	2.0 L/ha + 2.5 L/ha	30 g/L nicosulfuron; 75 g/L mesotrione + 450 g/L glyphosate (acid equivalent)
IV	Roundup Max	4.0 L/ha	450 g/L glyphosate (acid equivalent); 551 g/L as potassium salt of glyphosate

Source: *developed by the author*

The physiological state of plants was evaluated based on visual and morphological traits. The analysis included assessment of growth inhibition, disruption of morphogenesis in vegetative organs, the rate of dieback in apical and lateral growth points, and the plants' ability to regenerate after chemical treatment. Physiological changes were recorded 7, 14, and 30 days after herbicide application. During this period, observations included the appearance of leaf blade deformities, changes in growth intensity, partial or complete loss of turgor, development of chlorosis and tissue necrosis, as well as cessation of central shoot growth. The physiological effect of herbicides was determined by the nature and rate of symptom manifestation, allowing evaluation of the systemic activity of the compounds even in the absence of quantitative biochemical indicators.

Morphometric analysis was conducted to quantitatively assess the biological effectiveness of chemical control on *Heracleum sosnowskyi*. During the study, plant height, stem diameter at the base, leaf surface area (calculated from linear measurements of leaves), and the number of regenerated shoots after treatment were determined. Measurements were carried out on fixed monitoring plots before herbicide application and 30 days after treatment. The obtained data were used for comparative analysis between control and treated variants. Morphometric parameters allowed an objective assessment of the degree of growth inhibition, disruption of structural organisation, and the plants' regenerative capacity following chemical exposure.

Phenological observations were performed to determine the effects of herbicides on the developmental rhythm and generative cycle of *Heracleum sosnowskyi*. Throughout the growing season, the timing of key developmental phases was recorded, including regrowth, stem elongation, bud formation, and flowering, as well as shifts in phenological phases following herbicide treatment. Particular attention was given to delays or complete suppression of flowering processes and disruption in the formation of generative organs. Plants that failed to transition to the generative phase after treatment were considered a key indicator of high chemical control efficacy. Morphometric data were analysed using variance statistics to determine mean values and relative changes compared to the control. The technical effectiveness of herbicides was assessed based on the degree of plant growth suppression and the reduction in their regenerative capacity.

The methodology was developed based on a combination of peer-reviewed scientific literature, technical reports, and legal frameworks. Sources such as A. Čerevková *et al.* (2024), E. Borska *et al.* (2025), and A. Judžentienė *et al.* (2026) provided guidance on evaluating herbicide effects and systemic activity in invasive plants. The study was conducted in compliance with current ethical guidelines for plant research. Observations and herbicide applications were carried out in natural habitats without causing irreversible damage to surrounding ecosystems or endangered species. Additionally, all plant collections and interventions adhered to the CITES (Convention on international trade in endangered species of wild fauna and flora) (n.d.), confirming that no protected or regulated species were impacted during the study. The choice of these sources was justified by their international recognition, relevance to the research objectives, and applicability to invasive plant management under field conditions.

RESULTS AND DISCUSSION

The study of systemic herbicides on *Heracleum sosnowskyi* demonstrated pronounced growth inhibition and disruption of morphogenesis. Visual assessment of physiological traits showed that by the 7th day after treatment, plants began to exhibit leaf deformation, reduced turgor, and slowed apical growth. Symptoms intensified by the 14th day, with partial dieback of lateral shoots and the appearance of chlorosis and tissue necrosis. By 21-30 days, in treatment III (Elumis OD, 2.0 L/ha + Roundup Max RK, 2.5 L/ha), most plants experienced complete dieback of growth points, and regenerated shoots were weak and did not form generative organs. Treatments II (Slash KE, 1.5 L/ha) and IV (Roundup Max RK, 4.0 L/ha) exhibited less intensive growth suppression with a greater delay, confirming their limited systemic activity.

Data from Table 1 indicate significant differences in the growth and development of *Heracleum sosnowskyi* depending on the treatment applied. In the control, throughout the observation period, plants showed intensive growth with steady increases in all morphometric

parameters. By the 14th day, plant height nearly doubled compared to the 7th day, reaching 90 cm by the 30th day. Similar dynamics were observed for stem diameter and leaf area, indicating high adaptive capacity and active vegetative growth in the absence of herbicide influence. The number of regenerated shoots in the control also steadily increased, confirming the significant regenerative potential of *Heracleum sosnowskyi*.

Application of Slash caused moderate inhibition of growth processes. Although increases in height, stem diameter, and leaf area continued throughout the observation period, growth rates were significantly lower than in the control. By the 30th day, plant height in this treatment was more than twice as low as in the control, and leaf area decreased nearly threefold. The number of regenerated shoots also increased more slowly, indicating partial limitation of regenerative capacity, though without complete cessation of growth.

The most pronounced inhibitory effect was observed in the combined treatment of Elumis OD, 2.0 L/ha + Roundup Max RK, 2.5 L/ha. This treatment showed a clear trend of gradual reduction in all morphometric parameters over time. Plant height decreased from 22 cm on day 7 to 14 cm on day 30, indicating not only growth suppression but also degradation of aboveground biomass. Similar dynamics were observed for stem diameter and leaf area, reflecting disruption of photosynthesis and formation of vegetative organs. The number of regenerated shoots in this treatment remained minimal throughout the period, confirming effective blocking of *Heracleum sosnowskyi*'s regenerative mechanisms (Table 2).

Table 2. *Morphometric parameters of Heracleum sosnowskyi*

Treatment	Day	Height (cm)	Stem diameter (cm)	Leaf area (cm²)	Regenerated shoots
Control	7	25 ± 2	1.5 ± 0.2	180 ± 20	0.5 ± 0.1
	14	45 ± 4	2.5 ± 0.3	350 ± 35	1.0 ± 0.2
	21	65 ± 5	3.8 ± 0.4	600 ± 55	1.8 ± 0.3
	30	90 ± 7	5.0 ± 0.5	900 ± 80	2.8 ± 0.4
Slash KE. 1.5 L/ha	7	23 ± 2	1.4 ± 0.2	160 ± 18	0.4 ± 0.1
	14	30 ± 3	1.8 ± 0.2	220 ± 25	0.6 ± 0.2
	21	35 ± 4	2.1 ± 0.3	260 ± 30	0.7 ± 0.2
	30	40 ± 4	2.4 ± 0.3	300 ± 35	0.8 ± 0.2
Elumis OD. 2.0 L/ha + Roundup Max RK. 2.5 L/ha	7	22 ± 2	1.3 ± 0.2	150 ± 18	0.3 ± 0.1
	14	20 ± 2	1.2 ± 0.2	135 ± 16	0.26 ± 0.1
	21	17 ± 2	1.0 ± 0.1	115 ± 14	0.22 ± 0.1
	30	14 ± 2	0.8 ± 0.1	90 ± 12	0.2 ± 0.1
Roundup Max RK. 4.0 L/ha	7	24 ± 2	1.4 ± 0.2	170 ± 20	0.4 ± 0.1
	14	35 ± 3	2.0 ± 0.2	260 ± 30	0.7 ± 0.2
	21	45 ± 4	2.6 ± 0.3	340 ± 35	1.0 ± 0.3
	30	55 ± 5	3.2 ± 0.3	420 ± 40	1.3 ± 0.3

Source: *developed by the author*

In the treatment with Roundup Max RK alone (4.0 L/ha), pronounced but less intensive growth suppression was observed compared to the combined herbicide application. Although all parameters increased over time, their absolute values remained substantially lower than in the control. By the 30th day, plant height, stem diameter, and leaf area were maintained at levels indicating partial inhibition of growth processes, while the ability for vegetative regeneration was retained, as evidenced by the increase in the number of regenerated shoots.

Overall, the results indicate that *Heracleum sosnowskyi* exhibits high growth activity and significant regenerative potential in the absence of herbicide application. Herbicide treatments suppressed plant morphogenesis to varying degrees, with the most effective being the tank mixture of Elumis OD (2.0 L/ha) + Roundup Max RK (2.5 L/ha), which provided a consistent reduction in morphometric parameters and minimised regenerative processes. This treatment can be considered the most promising for controlling the spread of the invasive species *Heracleum sosnowskyi* in agro- and semi-natural ecosystems.

The data also clearly demonstrate the significant impact of herbicides on the phenological development of *Heracleum sosnowskyi*. In the control, most plants completed all stages of organogenesis: 100% reached the stem elongation phase, 90% reached bud formation, and 85% reached flowering. Application of Slash KE (1.5 L/ha) substantially restricted the transition of plants to subsequent phenological phases. The proportion of plants in the stem elongation phase decreased to 45%, more than halving compared to the control. Only 25% of plants reached

bud formation, and flowering was observed in just 5%, indicating strong suppression of generative development and a significant reduction in seed production potential (Fig. 1).

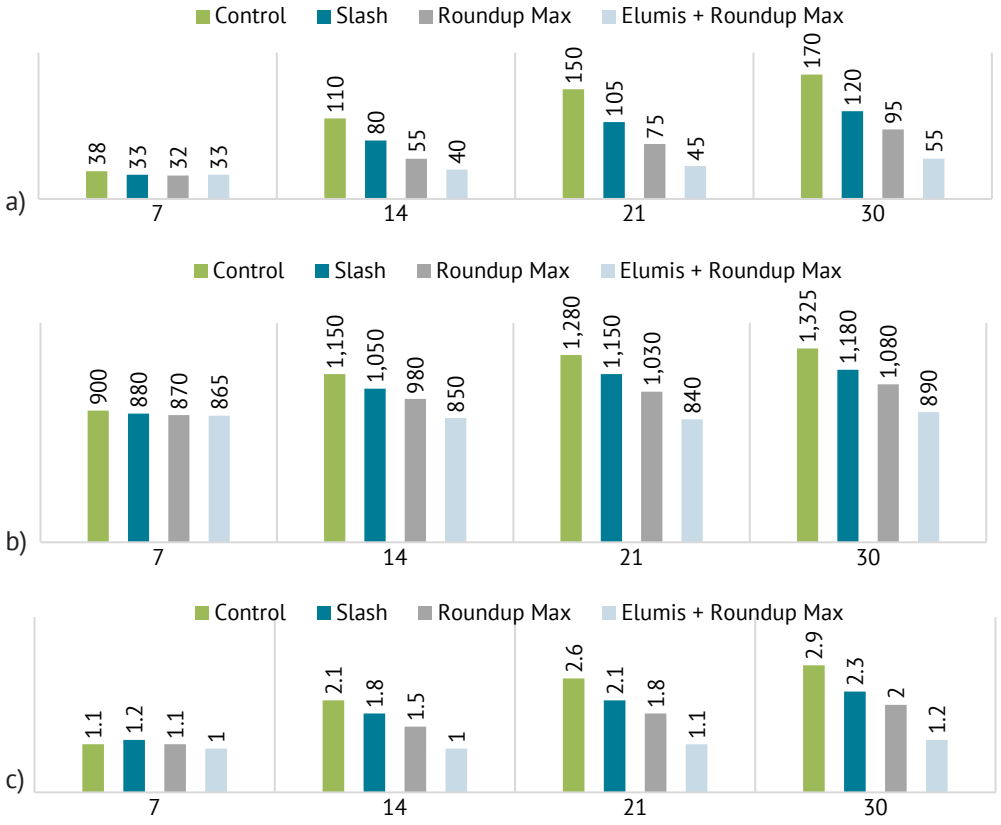

Figure 1. *Dynamics of growth (a), leaf area development (b), and regenerated shoots (c) of Heracleum sosnowskyi after treatment with different herbicides*

Source: *developed by the author*

The most pronounced effect was observed in the treatment with the tank mixture of Elumis OD (2.0 L/ha) + Roundup Max RK (2.5 L/ha). In this case, only 35% of plants reached stem elongation, which is 65% lower than in the control. Only 15% of plants reached bud formation, and the transition to flowering was completely blocked (0%). These results indicate full cessation of generative development under combined herbicide treatment. In the treatment with Roundup Max RK alone (4.0 L/ha), suppression of phenological development was less pronounced but remained significant. Stem elongation occurred in 50% of plants, bud formation in 30%, and flowering in 10%. Compared to the control, this represents an 8.5-fold reduction in the proportion of flowering plants, indicating a strong, though not complete, limitation of the species' reproductive capacity (Fig. 2).

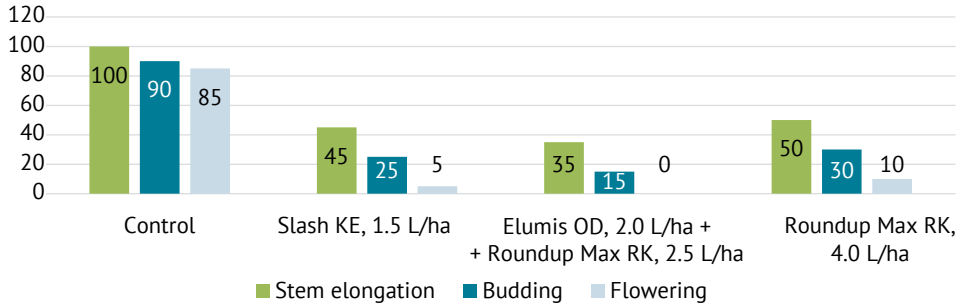

Figure 2. *Effect of herbicides on the phenological phases of Heracleum sosnowskyi (%)*

Source: *developed by the author*

A comprehensive analysis of physiological, morphometric, and phenological parameters showed that the highest efficacy in controlling *Heracleum sosnowskyi* is achieved through the combined application of Elumis OD (2.0 L/ha) and Roundup Max RK (2.5 L/ha). This tank mixture causes maximal growth suppression, delays generative development, and almost completely blocks regenerative capacity. Application of a single herbicide was less effective, due to the limited spectrum of action and slower systemic activity of individual compounds.

The results demonstrated the high effectiveness of systemic herbicides in controlling *Heracleum sosnowskyi*. Physiological observations revealed that this treatment rapidly suppresses apical and lateral growth, causes leaf deformation, turgor loss, and tissue necrosis within 7-14 days after application. Morphometric parameters confirmed these findings: plant height, stem diameter, and leaf area were reduced by 45-53%, and regenerated shoots were almost absent after 30 days. Phenological observations indicate complete blockage of transition to the generative phase, preventing seed formation and the establishment of a seed bank.

The results of the study showed that the most appropriate phase for the use of systemic herbicides is the rosette stage and the initial stages of intensive vegetative growth. During this period, plants showed increased sensitivity to the action of herbicides, which ensures maximum growth inhibition, disruption of morphogenesis and prevention of the formation of generative organs. Treatment at later stages, when the formed stems and leaves have already reached a significant mass, turned out to be less effective, since the plants partially retain the ability to regenerate and continue to enter the generative phase. It is considered that combining the chemical method with the mechanical one can significantly increase control effectiveness.Preliminary mowing or cutting of the above-ground mass allows to reduce the density of the thickets and at the same time improves the penetration of the working solution of the herbicide into the plant tissues. This approach not only increases the speed and depth of systemic action, but also prevents seed dispersal, which is especially important in urban and communal areas.

Based on the data obtained, a practical step-by-step control scheme for municipal services can be developed. It involves early detection of *Heracleum sosnowskyi* rosettes in the spring, the use of mechanical thinning where possible, and subsequent treatment with systemic herbicides in the early growth phase. Monitoring plant regeneration after 2-3 weeks allows for an assessment of the effectiveness of the initial treatment, and re-treatment of those shoots that have survived ensures complete blocking of regenerative mechanisms and prevents population recovery. The results also showed that a single treatment is often insufficient for complete control, especially in dense or perennial populations. Re-treatment 2-4 weeks after the initial herbicide application is necessary to eliminate residual shoots and prevent the formation of a soil seed bank. The combined application of Elumis OD (2.0 L/ha) and Roundup Max RK (2.5 L/ha) provides maximum growth suppression, blocking of generative development and almost complete elimination of regenerative capacity, making this approach the most promising for the control of *H. sosnowskyi* in agro- and semi-natural ecosystems. The integration of mechanical methods with a stepwise treatment strategy increases the long-term effectiveness and stability of control, reducing the risk of re-spreading of the invasive species.

These results were consistent with numerous Ukrainian and international studies, but a more detailed comparison provides additional insights. I. Shuvar *et al*. (2025) investigated the efficacy of systemic herbicides based on glyphosate, both alone and in combination with acetochlor or mesotrione, on perennial invasive species of *Apiaceae* and *Asteraceae*, including *Heracleum sosnowskyi* and *Solidago canadensis*. They measured growth suppression, morphometric changes, and generative development. Their results showed that combined herbicide treatments not only reduced leaf area and inhibited growth points but also effectively blocked the transition to generative phases, which aligns closely with received findings regarding the superior efficacy of the Elumis OD + Roundup Max mixture. It is widely accepted that early application during the rosette or early vegetative stage is critical for maximum effect.

In this direction, I. Gazoulis *et al.* (2022) also worked, who studied the effect of systemic herbicides on Heracleum mantegazzianum populations. The authors found that the use of glyphosate-containing preparations in the early phases of plant development provides a significant reduction in biomass, and also significantly inhibits the formation of generative organs. The researchers emphasised that the effectiveness of control increases significantly in the case of combining herbicides with different mechanisms of action, which confirms the feasibility of using tank mixtures for the control of *H. sosnowskyi*.

J. Soler & J. Izquierdo (2024) focused on the comparison of single versus combined systemic herbicide applications on invasive perennial plants. J. Soler & J. Izquierdo (2024) quantified morphometric parameters and regenerative potential over a 30-day period, demonstrating that tank mixtures produce faster and

more pronounced reductions in leaf area, stronger inhibition of apical and lateral growth, and near-complete suppression of regenerative shoots. These results corroborated present observations that combined treatments achieve greater systemic activity than single herbicides, confirming the advantage of multi-compound approaches in controlling *H. sosnowskyi*.

Similar results were obtained by W.-T. Gao & W.-H. Su (2024), who studied the regeneration ability of invasive perennial species after treatment with systemic herbicides. The authors found that the use of combined herbicide preparations contributes to the faster destruction of the photosynthetic apparatus of plants and significantly more effectively inhibits the formation of new shoots compared to single-component preparations. Therefore, this indicates the advantage of using tank mixtures for the control of aggressive invasive species.

X. Ye. *et al.* (2023) and I. Gruss *et al.* (2025) analysed herbicide sensitivity across different developmental stages of invasive plants. Both studies found that rosette-stage plants exhibit the highest susceptibility, while later stages such as stem elongation or bud formation show partial resistance due to more developed tissue and reduced systemic uptake. The current results are fully consistent with this pattern, as treatments applied in the early vegetative phases in the study performed achieved the greatest growth inhibition and almost complete blocking of generative development, while treatments in later stages were less effective.

Similar conclusions were obtained by L. Bobuľská *et al*. (2025), who studied the ecological features of invasive plants and their response to control measures. The authors emphasise that young plants of invasive species are characterised by significantly higher sensitivity to herbicides due to a less developed root system and more active processes of transport of active substances in tissues. This explains the higher efficiency of treatments carried out in the early phases of vegetation.

A. Valiño *et al*. (2023) investigated single-compound herbicide applications on perennial invasive species, reporting only partial growth inhibition and slower systemic action. While author confirmed the potential of glyphosate-based treatments, their findings highlighted the limitations of single-herbicide approaches. These observations are consistent with previous findings, where single-herbicide treatments (Slash KE or Roundup Max alone) suppressed growth and delayed development but did not completely prevent regeneration or flowering. Therefore, tank mixtures are considered preferable for achieving comprehensive control of *H. sosnowskyi*. In addition, recent studies have provided new perspectives on integrated and stepwise control strategies. For example, T. Žalnierius *et al*. (2025) examined the combination of chemical and mechanical methods in field populations of invasive plants, including *H. sosnowskyi*, and demonstrated that sequential mowing followed by systemic herbicide application significantly enhances suppression, reduces seed production, and minimises reinfestation risk. This complements the present findings and supports the practical recommendation to integrate mechanical removal with early chemical treatment, particularly in urban or semi-natural areas. K. Słowiński *et al*. (2024) evaluated phenological shifts in invasive species under herbicide treatment. The study demonstrated that early application of systemic herbicides not only delays or suppresses flowering but also reduces seed viability and limits long-term population establishment. These findings are directly consistent with the observations: the tank mixture of Elumis OD + Roundup Max completely blocked flowering and generative organ formation in *H. sosnowskyi*, confirming both immediate growth suppression and prolonged inhibition of reproductive capacity.

Similarly, T.I. Kose *et al*. (2025) investigated the effectiveness of combined herbicide applications on perennial invasive plants, including *Heracleum* species. They found that tank mixtures significantly reduce leaf area, suppress apical and lateral growth points, and limit regenerative potential, particularly when applied during early vegetative stages. These results align closely with this study, reinforcing the conclusion that early, combined chemical treatments provide the most reliable control of *H. sosnowskyi*, effectively minimising both vegetative and generative regeneration. Finally, I. Gruss *et al.* (2025) investigated the economic efficiency of chemical control of invasive perennial plants. Authors found that early application of systemic herbicides reduces the frequency of repeated treatments, lowers management costs, and prevents establishment of persistent seed banks. Thus, the results confirmed that timely early herbicide applications significantly reduce the need for re-applications, demonstrating the advantage of combination treatments in terms of cost and effectiveness.

Overall, the reviewed literature generally supported the present findings that systemic herbicides, particularly in tank mixtures, are most effective when applied at early vegetative stages. While single-herbicide applications provide partial control, combined treatments maximise growth inhibition, block generative development, and minimise regenerative potential. The consensus among these studies reinforces the importance of early detection, timing, and integrated chemical-mechanical strategies, which is consistent with the observed physiological, morphometric, and phenological responses

of *H. sosnowskyi* in the present study. The study confirmed that combined herbicide application is the most effective method for chemical control of *Heracleum sosnowskyi* under field conditions, providing maximal growth suppression, blocking generative development, and significantly reducing regenerative capacity. The results are consistent with international research and can be used to develop practical recommendations for managing invasive populations of *Heracleum sosnowskyi*.

CONCLUSIONS

The study demonstrated that *Heracleum sosnowskyi* exhibits high growth activity and a pronounced regenerative potential under control conditions (without herbicide application). After 30 days, plant height reached 90 ± 7 cm, stem diameter was 5.0 ± 0.5 cm, leaf surface area amounted to 900 ± 80 cm^2, and the number of regenerative shoots increased to 2.8 ± 0.4, indicating intensive vegetative growth and recovery capacity. Application of the herbicide Slash EC at a rate of 1.5 L/ha significantly suppressed plant growth. On the 30th day, plant height decreased to 40 ± 4 cm, stem diameter to 2.4 ± 0.3 cm, leaf area to 300 ± 35 cm^2, and the number of regenerative shoots was reduced to 0.8 ± 0.2.

Treatment with Roundup Max SL at rates of 2.5-4.0 L/ha resulted in moderate growth inhibition. On day 30, plant height reached 55 ± 5 cm, stem diameter was 3.2 ± 0.3 cm, leaf surface area amounted to 420 ± 40 cm^2, and the number of regenerative shoots was 1.3 ± 0.3, indicating partial suppression of vegetative growth and generative development. The highest efficacy was observed with the tank mixture of Elumis OD (2.0 L/ha) and Roundup Max SL (2.5 L/ha). Under this treatment, plant height on the 30th day was reduced to 14 ± 2 cm, stem diameter to 0.8 ± 0.1 cm, leaf surface area to 90 ± 12 cm^2, and the number of regenerative shoots remained minimal at 0.2 ± 0.1.

Analysis of phenological development revealed that in the control treatment, 100% of plants reached the stem elongation stage, 90% entered the budding stage, and 85% reached flowering. Application of Slash EC (1.5 L/ha) reduced these values to 45%, 25%, and 5%, respectively, while treatment with Roundup Max SL (4.0 L/ha) resulted in 50% stem elongation, 30% budding, and 10% flowering. In contrast, the tank mixture of Elumis OD (2.0 L/ha) and Roundup Max SL (2.5 L/ha) completely blocked the flowering stage (0%) and significantly limited stem elongation and budding (35% and 15% of plants, respectively).

The obtained results indicate that the combined application of Elumis OD (2.0 L/ha) and Roundup Max SL (2.5 L/ha) provides the most effective suppression of growth, generative development, and regenerative processes of *Heracleum sosnowskyi*, whereas the use of single herbicide treatments is less effective due to a narrower spectrum of action and slower systemic activity.Future research should focus on evaluating the long-term effects of repeated herbicide applications on soil seed banks and the potential development of herbicide resistance in *Heracleum sosnowskyi*. Additionally, studies could explore integrated management strategies that combine chemical, mechanical, and biological control methods to optimise both ecological and economic efficiency in different habitat types.

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Вплив гербіцидів на ріст та розвиток інвазивного виду *Heracleum sosnowskyi* Manden.

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Анотація. Метою дослідження було оцінити ефективність різних гербіцидних обробок щодо пригнічення росту, розвитку та регенераційних здібностей інвазійного виду *Heracleum sosnowskyi* Manden. Дослідження виконано з використанням чотирьох варіантів: контроль без гербіцидів, Слаш КЕ (1,5 л/га), Раундап Макс РК (4,0 л/га), а також комбіноване внесення Елюміс ОД (2,0 л/га) та Раундап Макс РК (2,5 л/га). Для оцінки ефекту гербіцидів визначали морфометричні показники рослин (висота, діаметр стебла, площа листків), фенологічні фази (стеблування, бутонізація, цвітіння) та кількість відновних пагонів у динаміці спостережень протягом 30 діб. Результати показали, що у варіанті контролю рослини характеризувалися високими темпами росту, значним збільшенням морфометричних показників та активною генеративною діяльністю, включно з формуванням відновних пагонів. Застосування одиночних гербіцидів призвело до часткового пригнічення росту та генеративного розвитку, при цьому відновні пагони утворювалися, хоча й у меншій кількості порівняно з контролем. Найбільш виражений ефект спостерігався за комбінованого внесення гербіцидів Елюміс ОД (2,0 л/га) та Раундап Макс РК (2,5 л/га). У цьому варіанті висота рослин, діаметр стебла та площа листків знижувалися до мінімальних значень, генеративний цикл практично блокувався, а кількість відновних пагонів залишалася стабільною або зменшувалася, що свідчить про повне пригнічення регенераційних механізмів *Heracleum sosnowskyi*. Практичне значення отриманих результатів полягає в тому, що комбінована гербіцидна обробка може бути ефективним методом контролю інвазійного виду в агроекосистемах і напівприродних угіддях, запобігаючи його поширенню та зменшуючи негативний вплив на продуктивність сільськогосподарських культур

Ключові слова: хімічний контроль; фізіологічна реакція; морфометричний аналіз; фенологічні зміни; контроль бур'янів