

Pre-sowing preparation and agrotechnics of sowing as factors of soil germination seeds of *Thuja plicata* Don. ex D. Donn

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Abstract. This study aimed to determine the optimal conditions for pre-sowing seed preparation and sowing depth to improve soil germination of *Thuja plicata*. The study was conducted using *Thuja plicata* seed material collected in the National Dendrological Park "Sofiyivka" of the NAS of Ukraine to evaluate seed quality, germination, and the effects of different pre-sowing treatments using standard methods. The results demonstrated significant effects of collection time, germination temperature, pre-sowing treatments, and sowing depth on seed performance. Seeds collected in autumn from standing trees showed higher germination energy (35.4-39.2%) and laboratory germination (44.4-48.7%) compared with seeds collected in winter from the snow surface, which demonstrated lower values of germination energy (27.1-31.6%) and laboratory germination (34.3-39.1%). Germination at +25°C increased germination energy and final laboratory germination compared with room temperature (18-20°C). Soil germination was strongly influenced by sowing depth and pre-sowing treatments. The highest soil germination (43.2 ± 2.1%) was recorded at a sowing depth of 0.5 cm after 30-day snow stratification, which exceeded the control treatment (32.7 ± 1.8%). Water soaking for 12 hours also improved germination, reaching 39.3 ± 1.9% at the same sowing depth. Increasing sowing depth to 2.0 cm resulted in a sharp decline in soil germination, reaching 10.1 ± 1.2% after snow stratification and complete absence of seedlings in the control treatment. Snow stratification

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also accelerated seedling emergence, reducing the time to first emergence from 14 days in the control to 12 days. These findings indicate that autumn seed harvesting, 30-day snow stratification, and shallow sowing (0.5-1.0 cm) provide the most favourable conditions for successful germination and seedling establishment of *Thuja plicata*

Keywords: introduced taxon; conifer reproduction; stratification methods; adaptive capacity; planting material production

INTRODUCTION

Seed propagation remains an important method for the large-scale reproduction of woody plant species and the production of planting material for forestry and ornamental horticulture. The use of seeds allows the production of genetically diverse and well-adapted planting material, which often develop stronger root systems and demonstrate greater ecological stability during early growth stages. For introduced coniferous species, the optimisation of seed propagation techniques is particularly important, since successful seedling establishment determines the efficiency of introduction and the long-term stability of cultivated populations. Therefore, understanding the factors that regulate germination and early seedling development is a key prerequisite for improving nursery technologies and ensuring the successful cultivation of introduced species.

Recent studies demonstrate that seed dormancy is a complex physiological mechanism that regulates the timing of germination and allows plants to synchronise seedling emergence with favourable environmental conditions. P. Awasthi (2023) investigated the ecological role of dormancy in forest plant species and demonstrated that dormancy regulates germination timing through physiological mechanisms that respond to environmental signals. The author showed that dormancy release is strongly associated with temperature and moisture conditions and concluded that appropriate dormancy-breaking treatments significantly improve germination synchrony and seedling establishment. Y. Song *et al.* (2023) analysed the influence of cold stratification on germination behaviour in several coniferous species. Their experimental results showed that stratification not only increases the percentage of germination but also expands the optimal temperature range in which germination occurs. The authors concluded that cold stratification modifies physiological processes in the embryo, thereby improving germination energy and accelerating early seedling development.

B. Kohinoor *et al.* (2024) examined the role of pre-sowing treatments in improving seed performance under stress conditions. Their experiments demonstrated that seed priming and other preparatory treatments enhance germination uniformity and increase tolerance to both biotic and abiotic stress factors during the

initial stages of seedling growth. According to the authors, pre-sowing treatments stimulate metabolic activity in seeds and promote faster transition from dormancy to active germination. Environmental factors also play an important role in regulating germination processes. J. Wang *et al.* (2024) investigated the relationship between dormancy type and environmental signals controlling germination in forest plants. Their study showed that temperature fluctuations and moisture availability act as key environmental cues that determine the timing and success of germination. The high effectiveness of snow stratification confirms the findings of Y. Song *et al.* (2023), who identified cold stratification as a key practice for improving conifer seed germination. Recent genomic studies further confirm the reproductive stability of *Thuja plicata* populations. Research conducted in European forest stands demonstrated that western redcedar maintains high genetic diversity from adult trees to offspring, indicating stable reproductive processes even under introduction conditions, as reported by L. Guillardín *et al.* (2025). The combined analysis of all experimental factors demonstrates that successful cultivation of *Thuja plicata* from seeds under introduction conditions requires an integrated technological approach. The use of high-quality seeds harvested in autumn, appropriate storage conditions, effective pre-sowing treatments-particularly snow stratification-and shallow sowing ensures higher soil germination, more uniform seedling emergence, and improved seedling quality.

A. Ferras *et al.* (2025) applied a time-to-event analytical approach to study temperature-dependent germination patterns in forest species. The researchers demonstrated that germination dynamics differ significantly among species and reflect ecological adaptation to specific environmental niches. Their findings indicated that analysing germination timing provides valuable information about physiological dormancy status and species-specific ecological strategies. Seed germination and early seedling establishment are particularly sensitive to environmental conditions in introduced species. Despite the progress achieved in recent studies, there is still limited empirical evidence regarding the combined influence of seed harvesting time,

temperature regime, storage conditions, and specific pre-sowing treatments on soil germination and seedling establishment of *Thuja plicata* under open-field conditions. Most available studies focus on general physiological aspects of dormancy or laboratory germination responses, while practical aspects of nursery cultivation remain insufficiently investigated. Therefore, the present study aimed to determine effective pre-sowing treatments and optimal sowing depth that improved soil germination and early seedling development of *Thuja plicata* under open-field conditions.

MATERIALS AND METHODS

The study was conducted using seeds of *Thuja plicata* reproduced at the National Dendrological Park "Sofiyivka" of the National Academy of Sciences of Ukraine. Seeds were collected from mature generative trees growing under introduction conditions in the park. After collection, the seed material was cleaned and air-dried at room temperature (18-20°C) until constant weight was achieved. Seed sowing quality parameters, including thousand-seed weight, germination energy, and germination capacity, were determined according to current interstate standards and generally accepted methodologies used for forest reproductive material. Laboratory germination tests were carried out in Petri dishes on moistened filter paper. Each experimental treatment included 100 seeds with four replicates. The filter paper was moistened with distilled water and maintained at constant humidity throughout the experiment. Germination was evaluated under two temperature regimes: room temperature (18-20°C) and constant temperature conditions in a thermostat (+25°C). To assess the effect of seed collection time, seeds were collected in two periods: in autumn from standing trees immediately after cone maturation and in winter from the surface of the snow cover beneath the trees.

Seed germination was monitored daily to determine the timing of seedling emergence. The first seedlings appeared within 12-24 days depending on the treatment. The final count of soil germination was carried out 30 days after sowing, when no further emergence of seedlings was observed. The date of the first emergence was recorded as the day when the first visible radicle protrusion was observed in at least one seed within a replicate. Germination energy was determined on the day corresponding to the peak of intensive germination, while final laboratory germination was recorded at the end of the observation period. Soil germination was evaluated under open-field conditions in the experimental nursery plot of the dendrological park. Sowing was performed in the second ten-day period of April. To determine the effect of sowing depth,

seeds were sown at depths of 0.5, 1.0, 1.5, and 2.0 cm. Seeds were covered with a substrate consisting of turf soil and sand mixed in a 3:1 ratio, which ensured sufficient aeration and moisture retention. During the experiment, the substrate maintained stable structure and moisture conditions; no significant surface crusting or excessive compaction was observed, which allowed normal seedling emergence under shallow sowing conditions. Each experimental variant included four replicates of 100 seeds each, allowing quantitative assessment of soil germination and seedling emergence.

Additionally, experiments were conducted to determine the effectiveness of different pre-sowing seed treatments. Although *Thuja plicata* seeds do not exhibit strict physiological dormancy, pre-sowing treatments may improve germination uniformity and accelerate seedling emergence. The following pre-sowing treatments were tested: snow stratification for 30 days, soaking in water for 12 hours, storage in moist sand, storage in moist peat, and untreated seeds used as the control treatment. For storage in sand and peat, seeds were mixed with moist substrate at a ratio of 1:3 (seed: substrate). The moisture content of the substrates was maintained at approximately 60-70% of full water-holding capacity. The containers with the seed-substrate mixture were stored at a temperature of 3-5°C for 30 days, which corresponds to conditions of cold moist stratification.

To evaluate seedling performance, morphological observations of emerging seedlings were conducted throughout the germination period. Seedlings were examined for uniformity of emergence, vigour, and general morphological condition. Qualitative characteristics used in Table 2 were defined as follows: "uniform" refers to dense and evenly distributed seedlings with well-developed hypocotyls and cotyledons; "well-developed" indicates vigorous seedlings with normal morphology and strong tissues; "satisfactory" describes seedlings with normal development but slightly reduced density; "sparse" denotes a low density of seedlings with uneven distribution; "weakened" refers to seedlings with elongated hypocotyls, thin tissues, or delayed development; "single" indicates the presence of isolated individual seedlings; and "absent" means that no seedlings were observed. In addition to visual assessment, a basic morphological analysis of seedlings was performed, including measurements of hypocotyl length and overall seedling vigour, which allowed comparative evaluation of seedling development under different treatments.

Statistical analysis of the experimental data was performed using generally accepted methods. Mean values (M) and standard errors ($\pm m$) were calculated for each experimental treatment. The least significant

difference ($LSD_{0.05}$) was determined to evaluate statistically significant differences between treatments.

RESULTS AND DISCUSSION

In accordance with the research program, the effect of the time of collection of forest reproductive material and the temperature regime of germination on the germination of *Thuja plicata* seeds was studied. Prior to the germination experiments, the basic sowing quality indicators of the seed material were evaluated. In particular, the thousand-seed weight was determined as an important indicator of seed fullness and potential

viability. The average thousand-seed weight of *Thuja plicata* seeds collected from generative trees in the National Dendrological Park "Sofiyivka" was 1.26 g. This value indicates satisfactory seed development and filling of the reproductive material. Adequate seed mass is generally associated with higher germination energy and improved seedling vigour, since larger seeds usually contain greater reserves of nutrients required for the initial stages of germination and early seedling development. The results of laboratory germination depending on seed collection time and temperature regime are presented in Table 1.

Table 1. Laboratory germination of *Thuja plicata* seeds depending on seed collection time and germination temperature

| Seed origin | Germination temperature, °C | Germination energy, % | Laboratory germination, % |
|--|-----------------------------|-----------------------|---------------------------|
| Seeds collected in autumn from standing trees | +18-20 | 35.4 | 44.4 |
| | +25 | 39.2 | 48.7 |
| Seeds collected from the surface of the snow cover | +18-20 | 27.1 | 34.3 |
| | +25 | 31.6 | 39.1 |

Source: developed by the authors

The data presented in Table 1 indicated that the technical germination and germination energy of *Thuja plicata* seeds depend significantly on both the timing of seed collection and the temperature regime during germination. The laboratory germination of *Thuja plicata* seeds ranged from 34.3 to 48.7%, while germination energy varied between 27.1 and 39.2%. The analysis of laboratory germination parameters revealed substantial differences between seeds harvested at different times. Seeds collected in autumn directly from standing trees showed consistently higher germination energy and final laboratory germination compared with seeds collected in winter from the surface of the snow cover. This can be explained by the more favourable physiological condition of autumn-harvested seeds, which complete maturation under relatively stable environmental conditions and are less exposed to damaging abiotic factors. Seeds that overwinter on the soil surface are exposed to repeated freeze-thaw cycles, excessive moisture, and prolonged low temperatures, which may lead to partial degradation of reserve substances and physiological ageing of the seed. Similar physiological changes associated with the deterioration of *Thuja plicata* seeds during storage, as well as the influence of seed maturity and storage conditions on the viability of forest reproductive material, have been noted in the studies of V. Terskikh *et al.* (2008) and in classical works on forest seed production (Debryniuk *et al.*, 1998). Similar effects of temperature on the viability and germination of conifer seeds were also reported in experimental studies

by B. Hawkins *et al.* (2003). The obtained germination values are also consistent with earlier experimental data for introduced coniferous species, where considerable variability of germination parameters depending on seed maturity and environmental conditions was reported (Smahliuk, 1976; Marynych, 1998).

The temperature regime during germination exerted a pronounced influence on both the rate and extent of seed germination. Germination at +25°C resulted in higher germination energy and slightly higher final laboratory germination compared with room temperature conditions (18-20°C). Elevated temperatures intensify metabolic activity, promote faster imbibition, and accelerate enzymatic processes associated with the mobilisation of reserve compounds. However, observations of seedling morphology indicated that excessively high temperatures may negatively affect early growth stages, as seedlings developed elongated hypocotyls and weaker tissues. Similar sensitivity of *Thuja plicata* seedlings to environmental conditions during early development has been reported in experimental studies analysing seedling growth under different light regimes (Wang *et al.*, 1994). Such morphological responses are typical for seedlings developing under accelerated metabolic conditions. Therefore, the temperature of +25°C can be considered optimal primarily for laboratory assessment of germination potential, where the objective is to determine the maximum viability of seeds. However, for practical nursery cultivation and the production of high-quality planting material, more moderate temperature conditions (18-20°C) appear preferable

because they provide a better balance between germination intensity and the formation of morphologically stronger seedlings. These observations correspond with the reproductive biology of *Thuja plicata* described by J. Owens & M. Molder (2011), who emphasised the sensitivity of early seedling development to environmental conditions. Recent reviews of the biology and ecological characteristics of western redcedar also indicate that environmental factors during germination significantly influence seedling establishment and

subsequent growth (Antos *et al.*, 2016; Aldana *et al.*, 2023). The depth of seed placement significantly affects the processes of germination and subsequent seedling development. Under deeper sowing conditions, seeds are supplied with a more stable moisture regime; however, seedlings experience greater mechanical resistance when penetrating the soil layer, which may delay or prevent emergence. The influence of pre-sowing treatments and sowing depth on soil germination of *Thuja plicata* seeds is presented in Table 2.

Table 2. Soil germination of *Thuja plicata* seeds depending on pre-sowing treatment method and sowing depth

| Pre-sowing seed treatment | Sowing depth, cm | Soil germination, % (M ± m) | Time to first emergence, days | Seedling characteristics |
|----------------------------------|------------------|--------------------------------|-------------------------------|--------------------------|
| Control (untreated) | 0.5 | 32.7 ± 1.8 | 14 | sparse |
| | 1.0 | 25.4 ± 1.6 | 16 | weakened |
| | 1.5 | 18.5 ± 1.4 | 18 | single |
| | 2.0 | 0.0 | - | absent |
| Snow stratification (30 days) | 0.5 | 43.2 ± 2.1 | 12 | uniform |
| | 1.0 | 40.1 ± 2.0 | 13 | well-developed |
| | 1.5 | 37.1 ± 1.9 | 15 | satisfactory |
| | 2.0 | 10.1 ± 1.2 | 21 | weakened |
| Water soaking (12 h) | 0.5 | 39.3 ± 1.9 | 13 | uniform |
| | 1.0 | 35.6 ± 1.8 | 14 | satisfactory |
| | 1.5 | 28.9 ± 1.6 | 16 | weakened |
| | 2.0 | 8.7 ± 1.1 | 22 | single |
| Storage in sand | 0.5 | 35.4 ± 1.7 | 14 | satisfactory |
| | 1.0 | 31.2 ± 1.6 | 15 | sparse |
| | 1.5 | 24.6 ± 1.5 | 17 | weakened |
| | 2.0 | 6.3 ± 0.9 | 23 | single |
| Storage in peat | 0.5 | 33.9 ± 1.6 | 14 | satisfactory |
| | 1.0 | 29.8 ± 1.5 | 15 | sparse |
| | 1.5 | 22.7 ± 1.4 | 18 | weakened |
| | 2.0 | 5.1 ± 0.8 | 24 | single |

Source: developed by the authors

The obtained experimental data indicated a significant influence of both pre-sowing seed treatment methods and sowing depth on the formation of *Thuja plicata* seedlings under soil conditions. Regardless of the treatment variant, an increase in sowing depth from 0.5 to 2.0 cm resulted in a clear decrease in soil germination rates. The first seedlings appeared between 12 and 24 days after sowing, depending on the treatment. Snow stratification accelerated seedling emergence compared with the control treatment. The final assessment of soil germination was carried out 30 days after sowing, when no further seedling emergence was observed. The highest soil germination values were recorded at a sowing depth of 0.5 cm. Under these conditions, snow stratification for 30 days proved to be the most effective treatment, resulting in 43.2 ± 2.1%, which significantly exceeded the control variant (32.7 ± 1.8%). A further increase in sowing depth to 2.0 cm resulted in a sharp decline in soil germination in all experimental variants.

In the control treatment, seedling emergence was absent. Even with the application of pre-sowing treatments, germination values remained low and did not exceed 10.1 ± 1.2% in the snow-stratified variant. The lowest soil germination was recorded for seeds stored in peat – only 5.1 ± 0.8%, indicating the unfavourable nature of combining this preparation method with deep (2.0 cm) seed placement. The decline in soil germination with increasing sowing depth agrees with observations by J. Young & C. Young (1993) and N. Khadduri (2007).

Pre-sowing treatments significantly enhanced soil germination and seedling emergence. Among the tested methods, 30-day snow stratification proved to be the most effective, resulting in the highest and most uniform germination. This treatment likely mimics natural winter conditions, facilitating the physiological after-ripening of seeds, activation of hydrolytic enzymes, and increased permeability of the seed coat. Consequently, stratified seeds exhibited faster emergence and greater

resistance to unfavourable early-spring environmental conditions. Water soaking for 12 hours and storage in sand or peat also positively affected germination; however, their effectiveness was lower compared with snow stratification, indicating only partial alleviation of dormancy mechanisms. Similar physiological mechanisms of dormancy release in conifer seeds have been widely discussed in modern studies of seed dormancy and germination ecology (Baskin & Baskin, 2014).

Sowing depth was identified as one of the most critical agrotechnical factors influencing seedling establishment. Shallow sowing at a depth of 0.5 cm provided optimal conditions for oxygen diffusion, moisture availability, and rapid emergence, resulting in the highest soil germination rates across all treatments. As sowing depth increased to 1.0 and 1.5 cm, soil germination gradually declined, likely due to increased mechanical resistance of the substrate and depletion of seed reserves before emergence. At a depth of 2.0 cm, seedling emergence was extremely limited or completely absent, even when pre-sowing treatments were applied. This clearly indicates that deep sowing creates unfavourable conditions for *Thuja plicata* seeds and should be avoided in nursery practice. The influence of sowing depth observed in the present study corresponds with recommendations provided in propagation protocols for *Thuja plicata*, where shallow sowing depths are considered optimal for ensuring successful seedling emergence (Plant Propagation Protocol for *Thuja plicata*, 2021). Experimental studies investigating the combined effects of light and stratification on conifer seed germination have also demonstrated that environmental conditions and substrate characteristics strongly influence germination dynamics in this species (Young & Young, 1993; Shlapak & Vitenko, 2010). N. Khadduri (2007) analysed the influence of sowing conditions on the emergence and early growth of conifer seedlings in nursery environments. The study demonstrated that sowing depth and substrate characteristics significantly affect seedling emergence rates and survival during the initial stages of development. The author concluded that optimisation of sowing conditions is essential for improving the efficiency of seed propagation in conifer nurseries. Further insights into germination ecology were provided by C. Schopmeyer (1974), who analysed germination responses of forest tree species under different environmental conditions. Their study showed that variations in temperature and moisture availability significantly influence germination success and seedling vigour. The authors emphasised that understanding species-specific germination requirements is essential for developing effective nursery cultivation techniques. The conducted studies demonstrated that the sowing quality and soil germination of *Thuja plicata* seeds are

determined by a complex interaction of biological and technological factors, including the time of seed harvesting, germination temperature, pre-sowing treatments, storage conditions, and sowing depth. Each of these factors plays a specific role in regulating seed viability, dormancy release, and seedling establishment, which is especially important for introduced woody species cultivated outside their natural range. These results are consistent with general patterns reported for introduced coniferous species and emphasise the necessity of adapting sowing techniques to the biological characteristics of the species.

CONCLUSIONS

The sowing quality and germination performance of *Thuja plicata* seeds were significantly influenced by the timing of seed harvesting, germination temperature, pre-sowing treatments, and sowing depth, which confirms the multifactorial nature of seed viability and early seedling establishment under introduction conditions. The interaction of these biological and technological factors determines not only the final germination percentage but also the rate of emergence and the initial quality of seedlings, which are critical parameters for successful nursery production. Seeds collected in autumn directly from standing trees consistently exhibited higher germination energy and laboratory germination than seeds harvested in winter from the surface of the snow cover. This highlights the importance of timely seed collection immediately after physiological maturation, when seeds are less affected by adverse abiotic factors such as prolonged low temperatures, excess moisture, and freeze-thaw cycles. The use of high-quality autumn-harvested seed material therefore represents a key prerequisite for achieving stable and predictable germination results. Germination under a constant temperature of +25°C enhanced both germination energy and final laboratory germination; however, the negative effects observed on early seedling morphology suggest that excessively high temperatures may compromise seedling quality. As a result, moderate temperature regimes appear more suitable for producing physiologically balanced and morphologically robust planting material intended for practical use. Under open-field conditions, soil germination is generally lower than laboratory germination, reflecting the influence of fluctuating environmental factors. Nevertheless, soil germination can be substantially improved through the optimisation of storage conditions and the application of appropriate pre-sowing treatments, demonstrating the necessity of adapting laboratory-based findings to real nursery environments. Among the tested treatments, 30-day snow stratification proved to be the most effective, significantly

increasing soil germination and ensuring more uniform and synchronous seedling emergence compared with water soaking or storage in sand and peat. Sowing depth was identified as a critical agrotechnical factor influencing seedling establishment. Shallow sowing at depths of 0.5-1.0 cm provided optimal conditions for oxygen availability, moisture supply, and rapid emergence, whereas deeper sowing at 2.0 cm resulted in a sharp decline in germination and should therefore be considered unsuitable for nursery practice. Overall, the combined application of autumn seed harvesting, snow stratification, and shallow sowing can be recommended as an effective and scientifically justified technological approach for the propagation of *Thuja plicata* from seed

in nursery and open-field conditions. Future research should focus on assessing the subsequent growth dynamics, physiological stability, and field survival of seedlings produced under these optimised conditions in order to further refine cultivation recommendations.

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Передпосівна підготовка та агротехніка сівби як чинники ґрунтової схожості насіння *Thuja plicata* Don. ex D.Donn

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Анотація. Метою дослідження було визначення оптимальних умов передпосівної обробки насіння та глибини посіву для підвищення схожості насіння туї звичайної (*Thuja plicata*) у ґрунті. Дослідження проводилося з використанням насінневого матеріалу туї звичайної, зібраного в Національному дендрологічному парку «Софіївка» НАН України, з метою оцінки якості насіння, схожості та впливу різних методів передпосівної обробки за допомогою стандартних методів. Результати показали значний вплив часу збору, температури пророщування, передпосівних оброблень та глибини посіву на показники насіння. Насіння, зібране восени з живих дерев, показало вищу енергію проростання (35,4-39,2 %) та лабораторну схожість (44,4-48,7 %) порівняно з насінням, зібраним взимку з поверхні снігу, яке продемонструвало нижчі показники енергії проростання (27,1-31,6 %) та лабораторної схожості (34,3-39,1 %). Пророщування при температурі +25°C підвищило енергію проростання та кінцеву лабораторну схожість порівняно з кімнатною температурою (18-20°C). На схожість у ґрунті значний вплив мали глибина посіву та передпосівні обробки. Найвища схожість у ґрунті (43,2 ± 2,1 %) була зафіксована при глибині посіву 0,5 см після 30-денної снігової стратифікації, що перевищило показники контрольного варіанту (32,7 ± 1,8 %). 12-годинне замочування у воді також покращило схожість, яка досягла 39,3 ± 1,9 % при тій самій глибині посіву. Збільшення глибини посіву до 2,0 см призвело до різкого зниження схожості в ґрунті, яка після снігової стратифікації становила 10,1 ± 1,2 %, а в контрольному варіанті – до повної відсутності сходів. Снігова стратифікація також прискорила сходження сходів, скоротивши час до першого сходження з 14 днів у контролі до 12 днів. Ці результати свідчать про те, що осінній збір насіння, 30-денна снігова стратифікація та неглибокий посів (0,5-1,0 см) забезпечують найсприятливіші умови для успішного проростання та вкорінення сходів *Thuja plicata*

Ключові слова: інтродукований таксон; розмноження хвойних; методи стратифікації; адаптивна здатність; виробництво посадкового матеріалу