MONOGRAPH

GREEN INFRASTRUCTURE, FOREST AND AGRICULTURAL SYSTEMS:

DEVELOPMENT AND RESTORATION UNDER CONTEMPORARY CHALLENGES

Tetiana Melnyk

SUSTAIN
RESTORE
THRIVE

GREEN INFRASTRUCTURE, FOREST AND AGRICULTURAL SYSTEMS: DEVELOPMENT AND RESTORATION UNDER CONTEMPORARY CHALLENGES

Monograph

According to the Scientific Edition
Candidate of Biological Sciences, Professor
Tetiana Melnyk

RS Global
Warsaw, Poland
2026

DOI: 10.31435/rsglobal/065

Recommended for publication by the Academic Council of Sumy National Agrarian University (№ 16 from 27.04.2026).

Reviewers:
Olga Bondarenko
Deputy Head of the Department of Architecture, Urban Planning and Cultural Heritage Protection of the Sumy City Council
Serhii Kotliarenko
Director of the State Enterprise "Trostianets Agrolisgosp"
Viktoriia Sosnytska
Head of Section at the Municipal Enterprise for Maintenance of Green Spaces of the Dnipro District of Kyiv

Authors:
Melnyk Andriy, Melnyk Tetiana, Chervona Vika, Horbas Serhii, Bakumenko Olha, Kriuchko Liudmyla, Butenko Sergey, Tokman Volodymyr, Osmachko Olena, Tetiana Boiko, Zhatova Halyna, Trotsenko Volodymyr and others.

Tetiana Melnyk (Ed.). (2026). *Green Infrastructure, Forest and Agricultural Systems: Development and Restoration Under Contemporary Challenges.* RS Global Sp. z O.O.

ISBN 978-83-970624-7-4 (eBook)

This monograph examines contemporary approaches to the sustainable development and management of forest, park, and agricultural systems in Ukraine under conditions of global environmental and socio-economic challenges. The publication integrates interdisciplinary research focused on biodiversity conservation, ecological restoration, agroforestry practices, ornamental horticulture, landscape architecture, and the improvement of green infrastructure. Particular attention is devoted to the adaptation of forestry and agricultural sectors to climate change, urbanization, and increasing anthropogenic pressure on natural ecosystems.
The monograph presents studies on the biological and ecological characteristics of plant species, cultivation technologies for ornamental and medicinal plants, productivity of agricultural crops, and the role of shelterbelts and fire protection systems in maintaining ecological stability. The authors analyze practical and scientific aspects of sustainable land use, spatial organization of natural and anthropogenic complexes, and the implementation of environmentally responsible management strategies based on international experience and modern environmental standards.
The research emphasizes the importance of integrated territorial planning and innovative approaches for strengthening Ukraine's ecological resilience and restoring natural resources. By combining theoretical foundations with practical recommendations, the monograph contributes to the development of effective mechanisms for environmental protection, sustainable agriculture, forestry modernization, and landscape management. The presented materials are intended for researchers, environmental specialists, agronomists, foresters, landscape architects, policymakers, and all professionals interested in sustainable ecosystem management and the advancement of green infrastructure in Ukraine.

ISBN 978-83-970624-7-4 (eBook)

TABLE OF CONTENTS

INTRODUCTION

The relevance of the study is due to the fact that effective organization and management of forest, park and agricultural complexes are fundamental factors of sustainable development and rational use of natural capital. These systems play a strategic role in maintaining ecological balance, preserving biodiversity, ensuring food security and creating conditions for recreation. However, modern global challenges, in particular climate change, rapid population growth, urbanization processes and intensification of agriculture, exert significant pressure on the environment, which requires the development and implementation of innovative management approaches.

In the context of these realities, a deep understanding of spatial relationships and the creation of effective management systems within natural and anthropogenic complexes acquires particular importance. The need to adapt to new climatic conditions, mitigate the consequences of environmental crises and preserve the integrity of natural ecosystems requires a comprehensive and integrated approach to land resource management. Scientifically based arrangement of territories allows not only to optimize the use of land plots and increase the productivity of the agricultural sector or the quality of the forest fund, but also to form a comfortable environment for the life of society. In addition, rational management contributes to the protection of soil and water resources, minimizing anthropogenic load on the environment. Thus, the study of the spatial organization of forest, park and agricultural objects is a crucial step towards ensuring a harmonious balance between economic interests, social needs and environmental requirements of modernity.

The materials presented in this monograph are united by a common goal: to make a significant contribution to the formation of a sustainable mechanism for the development and restoration of Ukraine's green infrastructure in the face of global challenges. The study covers strategically important sectors - forestry and agriculture, as well as landscape management of garden and park complexes. The authors' work is aimed at adapting theoretical achievements to modern realities, based on advanced international experience in restoring ecosystems and implementing standards of sustainable environmental management typical of developed countries. In view of this, the presented study is distinguished by scientific novelty and has high practical value for the development of an environmentally friendly economy.

The authors realize that the proposed conclusions are not final, since dynamic changes in the ecological and agrarian landscapes of Ukraine require constant updating of management approaches. The processes of restoration of natural resources and the transformation of forest and agricultural systems under the influence of modern crises dictate the need for continuous revision of the methodological foundations of sustainable development of territories. The monograph successfully combines logical sequence of presentation with high scientific accuracy. The work presents specific strategies and innovative models aimed at solving the current problems of strengthening green infrastructure and modernizing the agricultural and forestry sectors of Ukraine.

We express our sincere gratitude to the reviewers of this publication Olga Bondarenko, Deputy Head of the Department of Architecture, Urban Planning and Cultural Heritage Protection of the Sumy City Council; Serhii Kotliarenko, Director of the State Enterprise "Trostianets Agrolisgosp"; Viktoriia Sosnytska, Head of Section at the Municipal Enterprise for Maintenance of Green Spaces of the Dnipro District of Kyiv.

BIOLOGICAL CHARACTERISTICS AND DISTRIBUTION OF *VISCUM ALBUM* L. IN UKRAINE

Melnyk Tetiana
PhD of Biological Sciences, Department of Horticulture and Forestry,Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0002-3839-6018

Melnyk Andrii
Doctor of Agricultural Sciences, Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0001-7318-6262

Shvets Maryna
Ph.D. in Biological Sciences, Associate Professor, Polissia National University, Ukraine
ORCID ID: 0000-0002-1116-3986

Viscum album L. belongs to the Santalaceae family and represents a perennial evergreen hemiparasitic plant that colonizes a wide range of woody species, using them as a source of water and mineral nutrients. Despite possessing its own photosynthetic apparatus, which enables partial autotrophic nutrition, the plant remains physiologically dependent on its host. This dual nutritional strategy ensures high ecological plasticity and allows mistletoe to successfully persist both in natural forest ecosystems and in anthropogenically transformed environments, including urban and protective plantations [1, 9].

The life cycle of *Viscum album* typically spans 4 to 6 years and includes several distinct developmental stages: seed germination, haustorium formation, vegetative growth, flowering, and fruiting. The plant retains green leaves capable of photosynthesis throughout the year, including during winter dormancy of the host tree. This physiological feature provides a competitive advantage, as mistletoe remains metabolically active when host trees significantly reduce their physiological activity.

Morphologically, *Viscum album* forms a characteristic spherical crown with a diameter ranging from 20 to 100 cm, composed of repeatedly dichotomously branched shoots. Leaves are opposite, leathery, elliptical to lanceolate, 2–8 cm long, and light green in color. The flowers are small, yellowish-green, unisexual, and are pollinated both by wind and insects. The fruit is a globose pseudoberry, 7–10 mm in diameter, containing viscin – a sticky mucilaginous substance commonly referred to as “bird glue” [5, 12, 20].

Seed dispersal mechanisms differ among subspecies. Unlike *Viscum album* subsp. *album*, whose seeds are dispersed by numerous bird species, the dispersal of *Viscum album* subsp. *austriacum* is primarily associated with two bird species, notably the mistle thrush and the waxwing. These birds consume the fleshy viscin layer, while the sticky seeds adhere to their beaks. Subsequently, birds remove the seeds by wiping their beaks against branches, facilitating seed attachment to suitable host surfaces.

Following germination, a specialized organ – the haustorium – is formed. It penetrates the bark and cambial layers of the host tree and establishes a physiological connection with the xylem tissues. The initial developmental phase is relatively slow: during the first year, only the internal haustorial system develops, while the emergence of aerial shoots occurs 1–2 years after infection (Fig. 1). Flowering typically begins at the age of 4–5 years, and fruiting continues throughout the lifespan of the plant, which may reach 25–30 years [31].

Figure 1. Development of Viscum album individuals on the host plant [23].

The primary physiological mechanism of parasitism is based on the formation of an extensive haustorial system that extracts water and dissolved mineral nutrients directly from the host's xylem. Since mistletoe lacks a root system in the soil, it is entirely dependent on the host for water supply. Notably, the transpiration rate of mistletoe exceeds that of host tree leaves by 2–3 times, resulting in significant water stress within host tissues [16, 40, 41].

Numerous studies conducted in Central Europe have demonstrated that trees infected with mistletoe, particularly pines and poplars, may lose up to 40% of their annual increment. Infected trees exhibit reduced chlorophyll content, decreased photosynthetic activity, and premature dieback of shoots. Under drought conditions, mistletoe maintains high transpiration rates, while host trees reduce water loss, leading to xylem tension imbalance and physiological weakening of the host [22, 24, 26].

Despite its parasitic nature, *Viscum album* also plays a notable ecological role. Its fruits serve as an important food resource for birds during winter, while its dense crowns provide microhabitats for insects and avifauna. Consequently, some researchers consider mistletoe an indicator of ecosystem transformation and declining stability of forest stands.

However, excessive spread of mistletoe in natural forests and protective plantations disrupts biocenotic equilibrium. Infection levels exceeding 30 % of trees within a stand indicate degradation processes, loss of ecological functionality, and the necessity for implementing sanitary and silvicultural measures [12, 18].

In Ukraine, *Viscum album* is a widespread component of both forest and urban ecosystems (Fig. 2). The main distribution zones are concentrated within the Forest-Steppe and Polissya regions. Significant infection foci have been recorded in forest stands of Kyiv, Cherkasy, Poltava, Sumy, Zhytomyr and Volyn regions, where mistletoe commonly affects species such as *Populus alba*, *Salix alba*, *Acer platanoides*, *Tilia cordata*, *Fraxinus excelsior*, as well as certain coniferous species [4, 7, 13].

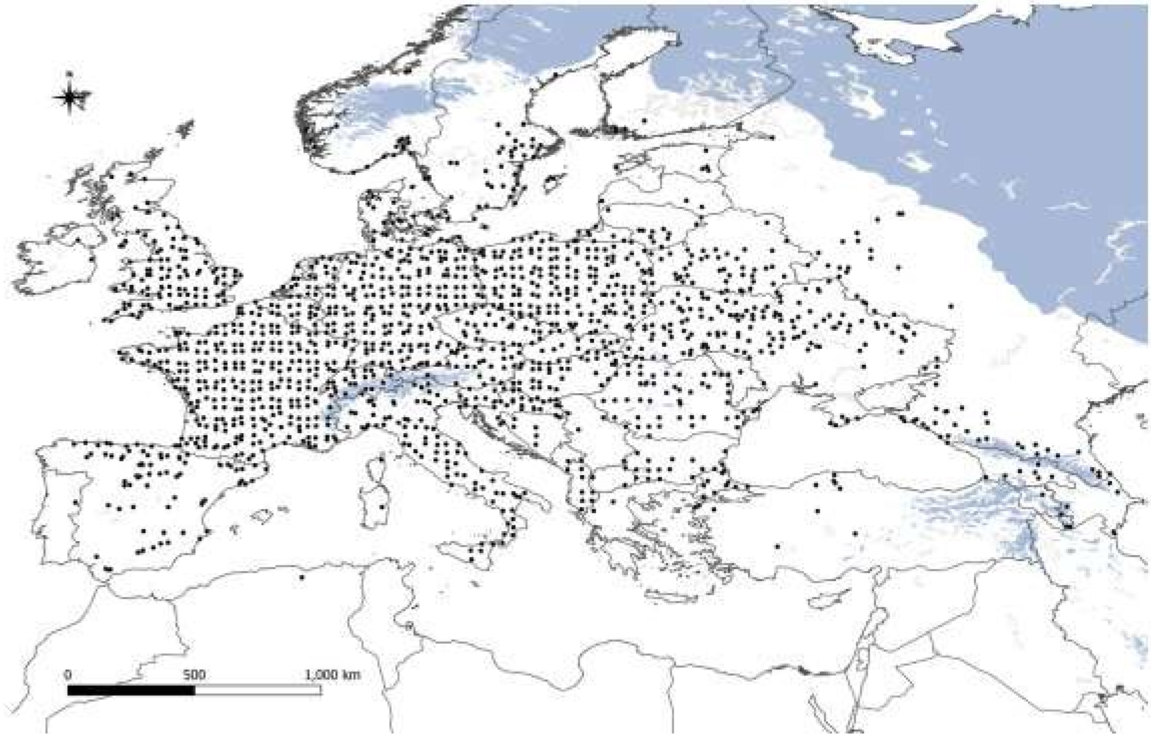


Figure 2. Occurrence of Viscum album in Europe [18].

Three subspecies are registered in Ukraine: *Viscum album* subsp. *album*, subsp. *austriacum*, and subsp. *abietis*. The first predominantly occurs in deciduous forests, the second in pine forests, while the third is mainly confined to the Carpathian region.

According to data reported in the Ukrainian Botanical Journal, the proportion of infected trees in floodplain forests of the Sumy region reaches 40–60% among stands older than 50 years. In recent years, an expansion of mistletoe distribution has been observed across Ukraine, largely attributed to climate warming, increased frequency of droughts, and the aging of forest stands.

The spread of mistletoe is particularly pronounced in degraded and thinned forests, where increased light availability and accessibility of branches for bird dispersers create favorable conditions for colonization. In the Forest-Steppe zone, especially within Sumy region, mistletoe is most frequently found on *Populus alba*, *Salix alba*, *Tilia cordata*, and *Acer platanoides*.

Within the forestry practices of the Romny agroforestry enterprise, infection hotspots are primarily associated with older age classes (50–70 years), particularly in shelterbelts and protective plantations. Most infected trees are located in open areas such as roadsides, agricultural fields, and river floodplains, where both insolation levels and bird activity are high [8, 13, 40].

Conversely, mistletoe is rarely found in dense young stands with closed canopies, which confirms its dependence on sufficient light availability for maintaining photosynthetic activity. Field observations indicate that approximately 35% of trees exhibit weak infection, 40% moderate infection, and 25% severe infection. The upper parts of the crown are most commonly affected, particularly branches aged 2–5 years, while skeletal branches are less frequently infected.

Viscum album is a significant factor contributing to the degradation of forest stands, especially in overmature plantations. The parasite intensifies water stress, reduces growth rates, and accelerates physiological aging processes in host trees. The loss of foliage above infection sites disrupts the balance of photosynthesis and negatively affects wood increment.

Studies conducted in Poland have shown that infected pine stands experience a reduction in annual growth by 41–64%, while needle density in the upper crown decreases by 30–50 %. Similar trends have been observed in pine forests of Zhytomyr and Volyn regions in Ukraine [19, 22, 41].

The decline in tree vitality increases susceptibility to secondary pests, including bark beetles and saprotrophic fungi, which further accelerate stand degradation. In deciduous forests, the consequences include reduced ornamental value, increased brittleness of branches, and heightened risk of tree failure, particularly in urban and recreational areas [9].

In summary, *Viscum album* is a typical hemiparasitic species that actively spreads in forest ecosystems of Europe and Ukraine, including the Sumy region. Its biological characteristics – such as year-round photosynthetic activity and high transpiration rates – contribute to its ecological success and persistence. Under conditions of climate change and forest aging, the intensity of infestation continues to increase, necessitating systematic monitoring and the implementation of appropriate forest management and sanitary measures.

The study of mistletoe distribution and impact is therefore of considerable importance for ensuring sustainable forest management, maintaining ecological balance, and enhancing the resilience of forest ecosystems in the Forest-Steppe zone of Ukraine.

Research Methodology. The research methodology was designed to ensure a comprehensive and integrated assessment of the distribution patterns of *Viscum album* L. within urban and peri-urban plantations, as well as to evaluate the infection load affecting trees of different species and age groups. The study combined classical forestry approaches with modern analytical techniques, including visual taxation methods, geobotanical surveys, biometric measurements, remote sensing techniques, and elements of geoinformation analysis. Such a multidisciplinary approach enabled both detailed field-level observations and large-scale spatial generalizations.

At the initial stage of the research, route-based field surveys were conducted across selected plantations. During these surveys, particular attention was paid to determining the species composition of stands, the general condition and vitality of trees, as well as the presence, density, and spatial configuration of mistletoe infection foci. Each tree within the surveyed plots was individually assessed.

A visual evaluation of the degree of infestation was carried out using a standardized five-grade scale commonly applied in forestry and phytopathological studies. This scale allows differentiation between weak, moderate, strong, and very strong levels of infestation, based on the number of mistletoe bushes and the proportion of the crown occupied by the parasite. The use of this widely accepted classification system ensured comparability and consistency of the obtained results with existing scientific data.

For *Populus alba* L., which proved to be one of the most susceptible host species, an additional quantitative assessment method was applied. This method involved the precise counting of mistletoe bushes on individual trees, followed by their classification according to size (diameter) and developmental stage (age). Such a detailed approach made it possible to evaluate the internal structure of the infection load and to identify patterns in the development and expansion of the haustorial system within the host tissues.

In parallel, morphological characteristics of mistletoe individuals were recorded. These included measurements of bush size, internode length of shoots, leaf coloration, and leaf morphometry. The analysis of these parameters provided additional insights into the physiological condition of the parasite and its degree of adaptation to specific host species. Variability in morphological traits was also considered as an indirect indicator of environmental conditions and host–parasite interactions.

To ensure precise spatial referencing of infected trees, GPS devices were used to record their geographic coordinates. The collected geospatial data were subsequently integrated into digital maps using geographic information systems (GIS). This enabled the identification of spatial distribution patterns of mistletoe, the delineation of high-density infection zones, and the analysis of relationships between infestation intensity and environmental factors.

For validation and visualization purposes, selected sites were subjected to detailed photographic documentation, including crown structure analysis and the assessment of structural damage caused by infestation. Additionally, remote sensing methods were applied, including photogrammetric surveys using unmanned aerial vehicles (UAVs) and the analysis of satellite imagery. These techniques allowed for the acquisition of generalized data on infestation patterns over large areas and significantly enhanced the reliability and representativeness of the results.

Special attention was given to identifying and evaluating environmental and biological factors influencing the intensity of mistletoe infestation. These factors included tree age, soil conditions, stand density, crown illumination, the presence of mechanical damage to trunks and branches, and the activity and abundance of bird dispersers. The integration of these variables allowed for a more comprehensive understanding of the ecological drivers of mistletoe spread.

Based on the collected empirical data, statistical analyses were performed to determine average infestation levels across different tree species and age groups. In addition, graphical models and diagrams were developed to visualize the distribution patterns of mistletoe within plantations. These analytical tools facilitated the identification of key trends, correlations, and spatial regularities, forming the basis for further interpretation and practical recommendations.

Bioecological features of the distribution of *Viscum album* and analysis of tree species resistance to infestation in the Sumy region. The distribution of *Viscum album* L. in the Sumy region represents a characteristic example of dynamic processes occurring within phytocoenoses under the combined influence of climatic and anthropogenic factors. Over recent decades, this species has demonstrated a pronounced tendency toward active range expansion, which can be attributed both to ongoing climate warming and to the progressive aging of tree stands. Under these conditions, mistletoe has emerged as one of the key biotic stress factors affecting the condition of deciduous, and to a lesser extent coniferous, tree species in the region. Its impact is particularly evident in shelterbelts, floodplain forests, and recreational plantations.

In the Sumy region, mistletoe predominantly occurs on deciduous tree species. The highest frequency of infestation is recorded on *Populus alba* L., *Salix alba* L., *Tilia cordata* Mill., *Betula pendula* Roth, *Acer platanoides* L., *Quercus robur* L. and *Ulmus laevis* Pall. In addition, mistletoe is occasionally found on fruit tree species such as *Malus domestica* Borkh., *Pyrus communis* L. and *Crataegus monogyna* Jacq. In contrast, infestation of coniferous species – such as *Pinus sylvestris* L. and *Abies alba* Mill. – is significantly less common and typically occurs in weakened stands or on isolated trees growing in open environments [14].

The increased susceptibility of trees in the region can be explained by the combined action of several factors, including stand aging, elevated air dryness, frequent summer droughts, and increased solar radiation. Mistletoe spreads particularly intensively in shelterbelt plantations, where the openness of tree crowns and high light availability create optimal conditions for seed germination and the establishment of young parasitic shoots. The highest proportion of infected trees is observed in age classes ranging from 40 to 70 years, corresponding to mature and overmature stands that gradually lose their natural resistance to external stressors.

The spatial distribution of mistletoe within the region is distinctly mosaic. Infection foci are most commonly formed in low-lying relief areas, near water bodies, in old parks, along forest edges, and in roadside plantations. In contrast, mistletoe is rarely found in dense forest stands with closed canopies, which clearly indicates its dependence on sufficient light conditions for successful establishment and development.

Seed dispersal is primarily mediated by birds, including thrushes, waxwings, and magpies, which feed on mistletoe berries during the winter period. These birds play a crucial role as dispersal agents, transporting seeds over considerable distances and thus ensuring the persistence and expansion of mistletoe populations within the region. This biological mechanism contributes to the formation of stable and self-sustaining populations across diverse habitats.

The impact of *Viscum album* on woody vegetation is complex and multifaceted, manifesting in physiological exhaustion, reduced growth rates, and decreased resistance of host trees. Infestation affecting more than 30% of the crown is considered critical, as it leads to disruption of the water balance, suppression of photosynthetic processes, and a decline in overall stand productivity. When infestation exceeds 60% of the crown area, trees typically lose their regenerative capacity and must be removed as part of sanitary measures.

In addition, infected trees become centers for secondary infestation by fungal pathogens and insect pests, which further accelerates their decline and increases the risk of stand destabilization. This is particularly important in protective and recreational plantations, where the loss of tree stability may pose ecological and safety risks.

The conditions in the Sumy region are characterized by a combination of natural and anthropogenic factors that facilitate the active spread of mistletoe. Climate change trends, including increasing average annual temperatures and decreasing precipitation, lead to frequent drought events and water deficits, particularly during the summer period. Under such conditions, physiologically weakened trees become more vulnerable to parasitic infestation.

In stands affected by windthrow or mechanical damage, mistletoe most frequently establishes on exposed branches in the upper crown layer, where light conditions are most favorable. This pattern further confirms the importance of insolation as a limiting factor for mistletoe development.

Control of *Viscum album* within the region is currently based primarily on mechanical methods. The most effective approach involves pruning infected branches along with a portion of healthy wood, typically at a distance of 15–20 cm below the point of parasite attachment. In cases of severe infestation, especially in shelterbelt plantations, selective or complete removal of heavily infected trees is recommended, followed by the establishment of young stands.

Removed branches and mistletoe bushes must be transported outside the plantation area and destroyed to prevent further seed dispersal. At present, no effective chemical control agents against mistletoe have been developed or approved in Ukraine. Therefore, management strategies are focused on preventive measures and systematic monitoring of plantation conditions.

For forestry enterprises in the region, including the Romny agroforestry branch, the control of mistletoe represents an ongoing task within the framework of sanitary and silvicultural measures. These activities are closely linked with the formation of younger and more resilient stands, where preference is given to tree species demonstrating higher tolerance to parasitic infestation.

Equally important are timely thinning operations, maintenance of optimal stand density, and preservation of biological diversity, all of which contribute to enhancing the overall resilience of forest ecosystems. Integrated forest management approaches are therefore essential for mitigating the negative impact of mistletoe.

In summary, *Viscum album* in the Sumy region represents a natural but currently overactive component of forest ecosystems. Its distribution is driven by a complex interaction of ecological, climatic, and anthropogenic factors, while the level of damage is directly dependent on the age structure and sanitary condition of tree stands. Improving the effectiveness of control measures requires a combination of continuous monitoring, preventive management, and the establishment of new plantations with a rational selection of resistant species. Such an approach will contribute to a gradual reduction in infestation levels and stabilization of forest ecosystem conditions in the region.

Classification of tree species according to resistance to *Viscum album* infestation. The classification of tree species according to their resistance to infestation by *Viscum album* L. is inherently conditional and is primarily based on long-term observational studies conducted by researchers between 2007 and 2024 across several regions of Ukraine, including Kyiv, Chernihiv, Zhytomyr, and Sumy oblasts. In addition to field observations, a substantial body of scientific literature authored by both Ukrainian and international researchers was analyzed, focusing on the distribution of mistletoe in Ukraine and across Europe. These sources provided valuable insights into the susceptibility and resistance of various woody species to infestation by this hemiparasitic plant.

The proposed classification should be considered indicative rather than absolute and may be refined through further long-term monitoring and experimental investigations. It reflects current trends in the changing resistance of tree species in urban and semi-natural environments, driven by climatic shifts, the physiological condition of stands, and the proximity of potential host plants that facilitate the spread of mistletoe [6, 9, 14].

Group I. Tree Species Resistant to *Viscum album*

This group includes species in which *Viscum album* has not been detected in tree crowns throughout the entire observation period, even when these trees were located in close proximity to heavily infested individuals of other species. Such resistance may be attributed to anatomical, physiological, or biochemical traits that inhibit haustorial penetration or reduce the suitability of host tissues for parasite development.

The following species belong to this group: *Ailanthus altissima* (Mill.) Swingle, *Carya illinoinensis* (Wangenh.) K. Koch, *Catalpa* spp. (all species and hybrids), *Celtis occidentalis* L., *Cornus mas* L., *Corylus colurna* L., *Fagus sylvatica* L., *Ginkgo biloba* L., *Gymnocladus dioicus* (L.) K. Koch, *Morus* spp. (all species), *Ostrya carpinifolia* Scop., *Platanus* spp. (all species), *Prunus avium* L. (including most ornamental cherry cultivars), *Quercus imbricaria* Michx., *Quercus palustris* Münchh., *Quercus robur* L., *Rhus typhina* L.

In addition, nearly all coniferous species belong to this group, including representatives of the genera *Picea*, *Thuja*, *Juniperus*, *Pseudotsuga*, *Chamaecyparis*, and *Taxus*. Exceptions include species of the genera *Pinus*, *Abies*, and *Larix*, which may be affected by other subspecies of mistletoe, such as *Viscum album* subsp. *austriacum* and *Viscum album* subsp. *Abietis* [14, 16, 19].

Group II. Relatively Resistant Tree Species

This group comprises species on which mistletoe infestation has been observed only sporadically, either on isolated individuals or mentioned in individual scientific reports. These species demonstrate a certain degree of tolerance, although under favorable environmental conditions or increased infection pressure, they may become susceptible.

The group includes: *Acer negundo* L., *Aesculus hippocastanum* L., *Alnus glutinosa* (L.) Gaertn., *Carpinus betulus* L., *Cercis canadensis* L., *Gleditsia triacanthos* L., *Liquidambar styraciflua* L., *Liriodendron tulipifera* L., *Magnolia* spp. (all species), *Prunus serotina* Ehrh., *Pyrus communis* L., *Quercus rubra* L., *Styphnolobium japonicum* (L.) Schott, *Ulmus* spp. (all species).

Group III. Highly Susceptible Tree Species

This group includes species in which mass infestation by *Viscum album* has been consistently recorded, often resulting in significant ecological and physiological impacts on host trees. These species typically possess structural or physiological characteristics that facilitate mistletoe establishment and proliferation.

The most susceptible species include: *Acer platanoides* L., *Acer pseudoplatanus* L., *Acer saccharinum* L., *Betula pendula* Roth, *Crataegus monogyna* Jacq., *Juglans nigra* L., *Malus* spp. (almost all species), *Populus* spp. (almost all species; less susceptible is *Populus nigra* var. *pyramidalis*), *Robinia pseudoacacia* L., *Salix* spp. (almost all species), *Sorbus aucuparia* L., *Tilia cordata* Mill.

The results of long-term observations clearly demonstrate that *Viscum album* possesses a broad spectrum of potential host species, predominantly among deciduous trees. The highest infestation intensity is observed in stands dominated by representatives of the families Salicaceae, Rosaceae, and Aceraceae, particularly *Tilia*, *Populus*, *Acer*, *Betula*, and *Robinia* species.

In contrast, coniferous species and certain introduced or exotic taxa exhibit either high tolerance or complete resistance to mistletoe infestation. These differences are likely related to variations in wood anatomy, chemical composition of tissues, bark structure, and physiological responses to stress.

The obtained results have significant practical importance for forestry and urban landscape management. In particular, they can be used to:

- optimize the selection of tree species for urban greening projects;
- design more ecologically stable and resilient green infrastructure;
- develop preventive strategies aimed at limiting the spread of *Viscum album*;
- support the implementation of targeted sanitary and silvicultural measures in affected areas.

Thus, the classification of tree species according to their resistance to mistletoe infestation serves as an important tool for improving the sustainability of urban and forest ecosystems, especially under current conditions of climate change and increasing anthropogenic pressure.

Analysis of the species composition of trees infected by *Viscum album* within the operational area of the Romny district

The results of field surveys indicate that the majority of trees affected by *Viscum album* L. within the study area belong to *Populus alba* L., which accounts for approximately 58 % of the total number of examined specimens. This clearly demonstrates the high susceptibility of this species and confirms its role as one of the primary host species facilitating the spread of mistletoe in protective and urbanized plantations.

Significantly lower infestation levels were recorded for other tree species. In particular, *Tilia cordata* Mill. accounts for about 10 % of the surveyed trees, while *Acer platanoides* L. and *Salix alba* L. each represent approximately 7–8 %. *Acer campestre* L. and other species collectively constitute around 5 % of the total (Fig. 3). This distribution reflects both species-specific susceptibility and the structural characteristics of the plantations under study.

The assessment of infestation levels was carried out using a standardized five-grade scale, which allows for a differentiated evaluation of parasite load on individual trees: 5 points – no signs of infestation; 4 points – weak infestation (up to 5 mistletoe bushes per tree); 3 points – moderate infestation (6–15 bushes); 2 points – strong infestation (16–24 bushes); 1 point – very strong infestation (25 or more bushes per tree).

This classification system ensures consistency in evaluating the severity of infestation and enables comparative analysis across species and sites.

For a more detailed analysis of infestation patterns, a representative sample of 30 individuals per species was selected, including *Fraxinus excelsior* L., *Robinia pseudoacacia* L., *Salix alba* L., *Tilia cordata* Mill., *Acer platanoides* L., *Aesculus hippocastanum* L., *Populus alba* L., *Acer campestre* L., and *Picea abies* (L.) H. Karst. The results of these observations are presented in Table 1.

The analysis of the obtained data indicates that the majority of examined trees exhibit either moderate or weak levels of crown infestation by mistletoe. However, a certain proportion of individuals with pronounced and locally high levels of damage was also recorded. On average, the infestation intensity for most studied species ranges between 3 and 4 points, corresponding to a moderate level of colonization. This suggests that mistletoe is stably present within the plantations, although its spread remains, to some extent, within a controllable range.

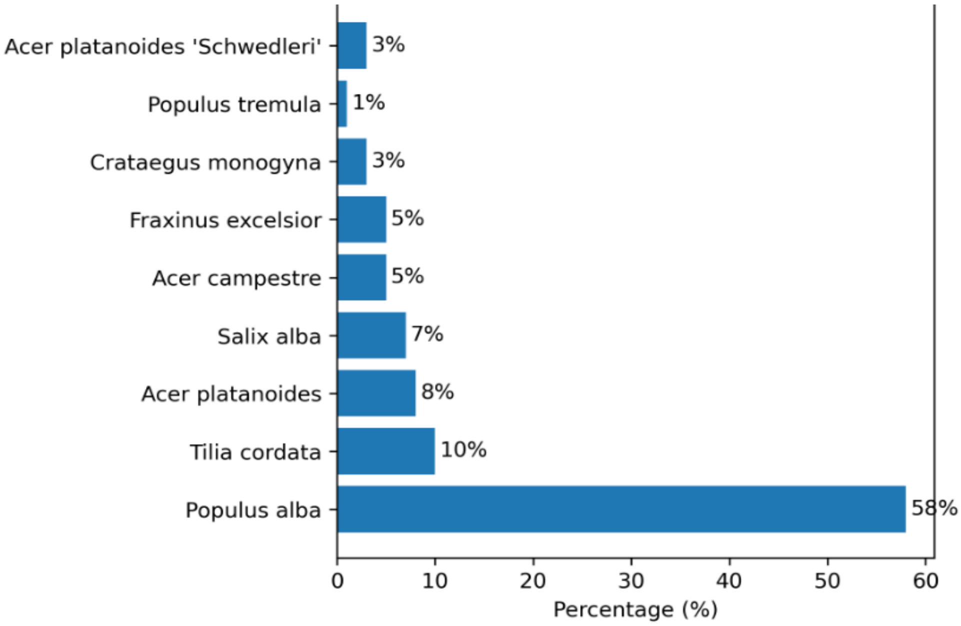


Figure 3. Species composition of woody plants infected by Viscum album in protective plantations of the Romny district

Such a distribution of infestation levels reflects not only species-specific characteristics but also the influence of tree age, crown architecture, and the degree of anthropogenic pressure in urban and peri-urban environments. The interaction of these factors determines both the vulnerability of host trees and the success of parasite establishment.

Table 1. Degree of infection of woody species by European mistletoe

Plant name	Degree of damage, score
Picea abies	1
Acer campestre	4
Acer platanoides	4
Aesculus hippocastanum	1
Fraxinus excelsior	2
Robinia pseudoacacia	3
Populus canadensis	4
Populus alba	5
Salix alba	1
Tilia cordata	2

According to the generalized assessment of settlements within the protective plantations of the Romny district, the most heavily infested species include *Populus nigra* L., *Fraxinus excelsior* L., *Acer platanoides* L., *Acer campestre* L., *Robinia pseudoacacia* L. and *Salix alba* L. These species typically exhibit a moderate to high degree of infestation (3–5 points), characterized by the formation of numerous mistletoe bushes in the upper crown layers (Fig. 4).

Figure 4. Visual examples of different degrees of tree infestation by Viscum album in the study region.

This pattern is primarily explained by the ecological preferences of mistletoe, which favors well-illuminated parts of the crown. Branches aged 2–5 years provide optimal conditions for seed germination and haustorium development. In contrast, infestation of skeletal branches and the central stem occurs less frequently, highlighting the light-dependent nature of parasite development and its adaptation to actively growing peripheral shoots.

To identify age-related patterns in mistletoe distribution, the examined trees were grouped into age categories. This approach allowed for the analysis of ontogenetic dynamics of infestation and the evaluation of changes in tree resistance throughout their lifespan.

The results demonstrate that the highest levels of infestation are observed in trees aged 50–60 years and older. In these age groups, infestation intensity increases significantly: the number of mistletoe bushes per tree often exceeds 20–25 individuals, and infection foci may cover a substantial portion of the crown.

In contrast, trees belonging to younger age groups (up to 30 years) exhibit either sporadic infestation or no signs of infection at all. This can be explained by several factors, including the morphological characteristics of young trees-such as dense crown structure, high growth rates, and active shoot regeneration − as well as their generally higher physiological resistance, which limits the successful establishment of mistletoe.

The proportion of infected trees in the 60–80-year age group averages 25–29 %, indicating a gradual decline in natural resistance and an increased vulnerability to biotic stressors with age (Fig. 5).

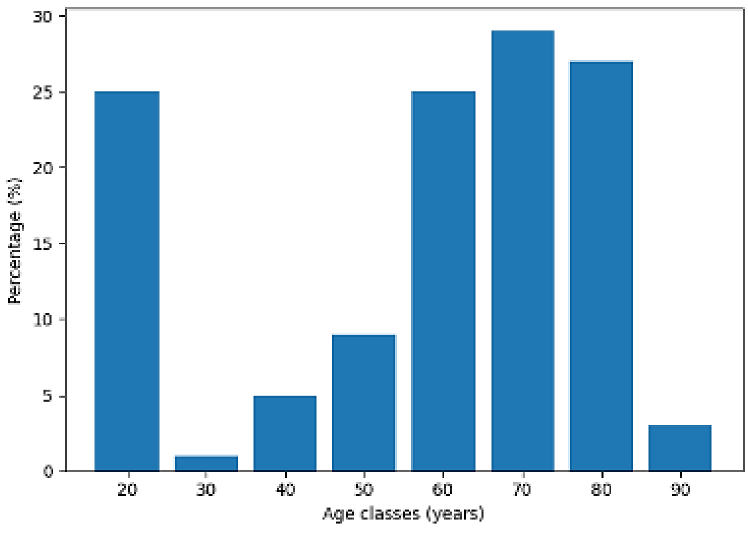


Figure 5. Age structure of plantations affected by Viscum album in protective plantations of the Romny district.

Thus, the relationship between tree age and mistletoe infestation intensity is clearly expressed and predictable. As trees approach maturity and overmaturity, infestation levels increase not only due to physiological weakening but also as a result of changes in crown architecture. Older trees tend to have more open and fragmented crowns, which are more accessible to bird dispersers.

Furthermore, mature trees provide a larger surface area of branches suitable for colonization, while localized reductions in bark thickness facilitate haustorium penetration. These factors collectively contribute to the selective colonization of older trees by mistletoe.

In summary, *Viscum album* exhibits pronounced ecological and ontogenetic selectivity, preferentially colonizing trees of middle and older age classes. This finding has important implications for the planning and implementation of measures aimed at improving the sanitary condition of urban and protective plantations. Incorporating age structure and species composition into management strategies will significantly enhance the effectiveness of efforts to control mistletoe spread and maintain the stability of forest ecosystems.

Discussion and Prospects for Further Research. The obtained results confirm that *Viscum album* is a highly adaptive hemiparasitic species with a broad ecological amplitude and a pronounced ability to colonize a wide range of deciduous host plants. The observed distribution patterns within protective plantations of the Romny district are generally consistent with previously reported data for Eastern Europe, indicating that species of the genera *Populus, Acer, Tilia*, and *Salix* represent the most vulnerable hosts under current environmental conditions.

The predominance of *Populus alba* among infected trees (up to 58%) highlights its key role in maintaining and spreading mistletoe populations in anthropogenically transformed landscapes. This finding is particularly important for the design of urban and protective plantations, where the use of highly susceptible species may significantly accelerate the formation of infection foci.

The classification of tree species according to their resistance to mistletoe infestation should be considered dynamic and context-dependent, as it reflects not only inherent biological traits but also the influence of external factors such as climate change, air pollution, and stand condition. The increasing frequency of drought stress and temperature fluctuations may weaken host resistance and create more favorable conditions for mistletoe establishment, especially in urban and peri-urban environments.

A clear relationship between tree age and infestation intensity was identified. Older trees (50–80 years) were significantly more affected, which can be explained by a combination of physiological weakening, structural changes in crown architecture, and increased attractiveness for bird-mediated seed dispersal. In contrast, younger trees demonstrated higher resistance, likely due to active growth processes and denser crown structures.

The results also emphasize the importance of light availability for mistletoe development. The concentration of mistletoe bushes in the upper and well-illuminated parts of the crown confirms the light-demanding nature of this species and its ecological strategy focused on peripheral shoot colonization.

From a practical perspective, the findings provide a scientific basis for improving the management of protective and urban plantations. In particular, they support the need to:

– limit the use of highly susceptible species in new plantings;
– prioritize resistant or relatively resistant taxa in landscape design;
– implement regular sanitary measures (selective pruning, removal of heavily infested trees);
– consider stand age structure when planning plantation reconstruction.

Prospects for Further Research. Further research on Viscum album should be oriented toward a comprehensive and integrative understanding of its ecology, host interactions, and management. In particular, sustained long-term monitoring is essential to identify temporal trends in host susceptibility and to evaluate the dynamics of mistletoe spread under ongoing climatic changes. At the same time, in-depth studies of physiological and biochemical resistance mechanisms at anatomical and molecular levels would provide valuable insights into the factors determining host tolerance or vulnerability.

An important research priority is the assessment of abiotic stress factors, including drought, temperature extremes, and soil conditions, which may significantly influence the establishment and development of mistletoe. In parallel, the development of predictive models that incorporate species composition, stand age structure, and landscape connectivity is necessary to improve forecasting accuracy and support decision-making in forest and urban ecosystem management.

Moreover, further investigations should address ecosystem-level effects, particularly the impact of mistletoe on productivity, biodiversity, and overall ecosystem stability. Finally, the development of integrated management approaches – combining silvicultural, ecological, and biotechnical methods, such as the regulation of bird-mediated seed dispersal and targeted pruning – represents a promising direction for enhancing the effectiveness of control strategies.

In general, the study of mistletoe infestation remains a highly relevant research area, particularly in the context of climate change and increasing anthropogenic pressure on forest and urban ecosystems. Expanding the scientific understanding of this host–parasite system will contribute to the development of sustainable strategies for maintaining the health and resilience of green infrastructure.

Conclusions. The conducted study demonstrates that Viscum album is widely distributed within protective plantations of the Romny district and exhibits pronounced host selectivity. The highest susceptibility was observed in representatives of the genera Populus, Fraxinus, Acer, and Salix, which play a key role in maintaining and spreading mistletoe populations. In contrast, certain species and forms, including Robinia pseudoacacia, Tilia cordata, and columnar poplar cultivars, showed relatively higher resistance, indicating their potential suitability for use in sustainable planting design.

The intensity of mistletoe infestation is strongly influenced by the age structure and morphological characteristics of host trees. The highest levels of infection were recorded in middle-aged and older stands (50–80 years), whereas younger trees (up to 30 years) exhibited only sporadic or no infestation. This pattern reflects age-related changes in physiological resistance, as well as structural transformations of the crown.

Crown architecture and anatomical features of host plants significantly determine the success of mistletoe establishment. Open, well-illuminated, and structurally heterogeneous crowns create favorable conditions for seed germination and haustorium development, particularly on peripheral shoots aged 2–5 years. In contrast, dense crowns and active growth processes in younger trees limit parasite establishment.

The distribution of mistletoe within tree crowns is non-uniform and primarily concentrated in the upper, well-lit parts, confirming its ecological dependence on light availability. This feature reflects the adaptive strategy of the species and should be taken into account when planning control measures.

The obtained results highlight the importance of species selection and stand management in reducing the spread of mistletoe. Incorporating resistant or relatively resistant species, considering stand age structure, and implementing timely sanitary measures are essential components of effective management strategies aimed at maintaining the ecological stability of protective and urban plantations.

REFERENCES

1. Ahmed Z. and Dutt H.C. Restriction of Viscum album to few phorophytes in a habitat with diverse type of tree species, Austin. J. Plant. Biol., 2015, 1, 2, 101–105.
2. Barbu C.O. Impact of white mistletoe (Viscum album ssp. abietis) infection on needles and crown morphology of silver fir (Abies alba Mill.), Not. Bot. Hort. Agrobot., 2012, 40, 2, 152–158. https://doi.org/10.15835/nbha4027 906
3. Bardini M., Lee D., Donini P. Tubulin-based polymorphism (TBP): a new tool, based on functionally relevant sequences, to assess genetic diversity in plant species, Genome, 2004, 47, 281–291. https://doi.org/10.1139/g03-132
4. Barney C.W., Hawksworth F.G., Geils B.W. Host of Viscum album, Eur. J. Forest. Pathol., 1998, 28, 187–208. https://doi.org/10.1111/j.1439-0329.1998.tb01249.x
5. Bilan M.V., Henyk A.O. (2019) Distribution of Viscum album in woody plantations of cities in Central Ukraine. Visnyk of Dnipropetrovsk University. Biology Series, 27(2), 54–63. https://doi.org/10.15421/021907
6. .Bondar O.S., Doroshenko S.A. (2021) Features of infestation of woody plantations by Viscum album in green zones of cities in Sumy region. Scientific Bulletin of Sumy National Agrarian University. Agronomy and Biology Series, 42, 88–94.
7. Bilgili E., Kadir Coskuner A., and Baysal I., The distribution of pine mistletoe (Viscum album ssp. austriacum) in Scots pine (Pinus sylvestris) forests: from stand to tree level, Scand. J. Forest Res., 2020, 35, 1–2, 20–28. https://doi.org/10.1080/02827581.2020.1729402
8. Bilonozhko O. M., Holubets M. A., & Zub L. M. Genetic polymorphism and host specificity of Viscum album L. in Eastern Europe. Ukrainian Botanical Journal, 2021, 78(3), 45–57. https://doi.org/10.15407/ukrbotj78.03.045.
9. Bilonozhko Y. O., Rabokon A. M., Postovoitova A. S., Kalafat L. O., Privalikhin S. M., Demkovych A. Ye., Pirko Ya. V. Some characteristics of woody plants inhabited by Viscum album (Santalaceae) in the city of Kyiv. Ukrainian Botanical Journal, 2020, 79(6), 388–396.
10. Bilonozhko Y., Ponomarenko L.O., Rabokon A.M. Distribution of mistletoe (Viscum album L.), which parasitizes different woody plants species, in Kyiv and its genetic characteristics, Factors Experim. Evol. Organisms, 2019, 25, 106–110. https://doi.org/10.7124/FEEO.v25.1148

11. Bohling N., Greuter W., Raus T. Notes on the Cretan mistletoe, Viscum album subsp. creticum subsp. nova (Loranthaceae/Viscaceae), Israel. J. Plant Sci., 2002, 50, 77–84. https://doi.org/10.1560/RRJ4-HU15-8BFM-WAUK
12. Braglia L., Gavazzi F., Giovannini A. TBP-assisted species and hybrid identification in the genus Passiflora, Mol. Breed., 2014, 33, 1, 209–219. https://doi.org/10.1007/s11032-013-9945-6
13. Breviario D., Baird W.V., Sangoi S. High polymorphism and resolution in targeted fingerprinting with combined β-tubulin introns, Mol. Breed., 2007, 20, 3, 249–59. https://doi.org/10.1007/s11032-007-9087-9
14. Chakraborty D., Móricz N., Rasztovits E., Dobor L. Schueler S. Provisioning forest and conservation science with European tree species distribution models under climate change (Version v1). Zenodo https://doi.org/10.5281/zenodo.3686918 (2020).
15. Galasso I., Manca A., Braglia L. h-TBP: an approach based on intron-length polymorphism for the rapid isolation and characterization of the multiple members of the β-tubulin gene family in Camelina sativa (L.) Crantz., Mol. Breed., 28, 635–645. https://doi.org/10.1007/s11032-010-9515-0
16. Galkin S.I., Dragan N.V., Doyko N.M. Mistletoe in the relations system of "host–parasite," Plant Introd., 2017, 3, 71–78. doi 10.5281/zenodo.2325002
17. Holubets M.A., Bilonozhko O.M. (2020) Anatomical structure of the haustorium of Viscum album on different deciduous tree species in Ukraine. Ukrainian Botanical Journal, 77(4), 33–42. https://doi.org/10.15407/ukrbotj77.04.033
18. .Kornus L.A., Pashkevych N.O. (2018) Assessment of resistance of woody plantations to Viscum album in urban ecosystems of Right-Bank Ukraine. Agroecological Journal, 2, 115–121.
19. Kartoolinejad D., Hosseini S.M., Mirnia S.K. The relationship among infection intensity of Viscum album with some ecological parameters of host trees, Int. J. Environ. Res., 2007, 1, 2, 143–149.
20. Kim B.Y., Park H.S., Kim S. Development of microsatellite markers for Viscum coloratum (Santalaceae) and their application to wild populations, Appl. Plant Sci., 2017, 5, 1. https://doi.org/10.3732/apps.1600102
21. Kim Ch.S., Kim S.Y., Sun B.Y. A review of the taxonomic and ecological characteristics of Korean mistletoe types (Viscum, Korthalsella, Loranthus and Taxillus), Korean J. Pl. Taxon, 2013, 43, 2, 81–89. https://doi.org/10.11110/kjpt.2013.43.2.81
22. Kolodziejek J., Patykowski J., Kolodziejek R., Distribution, frequency and host patterns of European mistletoe (Viscum album subsp. album) in the major city of Lodz, Biologia, 2013, 68, 1, 55–64. https://doi.org/10.2478/s11756-012-0128-4
23. Krasylenko Y., Klymenko S., & Martynenko I. Patterns of distribution and host selectivity of Viscum album in urban woody plants of Northern Ukraine. Urban Forestry & Urban Greening, 2023, 88, 128034. https://doi.org/10.1016/j.ufug.2023.128034.
24. Krasylenko Y., Sosnovsky Y., Atamas N. The European mistletoe (Viscum album L.): distribution, host range, biotic interactions, and management worldwide with special emphasis on Ukraine, Botany, 2020, 98, 9. https://doi.org/10.1139/cjb-2020-0037
25. Krasylenko Y., Sosnovsky Y., Atamas N., Popov G., Leonenko V., Janošíková K., Sytschak N., & Sytnyk D. (2020). The European mistletoe (Viscum album L.): distribution, host range, biotic interactions, and management worldwide with special emphasis on Ukraine. Botany, 98(9).
26. Lech P., & Żółciak A. Occurrence of European Mistletoe (Viscum album L.) on forest trees in Poland and its dynamics of spread in the period 2008-2018. Forests, 11(83).
27. López de Buen L., Ornelas J. F. Host compatibility of mistletoes: Physiological drivers and ecological consequences. Ecology Letters, 2011, 14(2), 127–134.
28. Lyubov O. Some characteristics of woody plants that are colonised by Viscum album (Santalaceae) in the city of Kyiv. Ukrainian Botanical Journal, 2022, 79(6), 388–396.
29. Malova T. I., Mashtaler O. V. Morphobiological characteristics of development of Viscum album in the conditions of urbanised environment of Vinnytsia, Ukraine. Chornomorski Botanical Journal, 2024, 20(4), 471–481.
30. Mejnartowicz L. Relationship and genetic diversity of mistletoe (Viscum album L.) subspecies, Acta Soc. Bot. Polon., 2006, 75, 1, 39–49. https://doi.org/10.5586/asbp.2006.007
31. Milewicz M., Sawicki J. Sex-linked markers in dioecious plants, Plant Omics, 2013, 6, 2, 144–149.
32. Nei M., Li W.H. Mathematical model for studying genetic variation in terms of restriction endonucleases, Proc. Natl. Acad. Sci. U. S. A., 1979, 76, 5269–5273.
33. Pannell J.R. Plant sex determination, Curr. Biol., 2017, 27, 5, 191–197. https://doi.org/10.1016/j.cub.2017.01.052
34. Pavlicek A., Hrda S., Flegr, J. FreeTree—freeware program for construction of phylogenetic trees on the basis of distance data and bootstrap/jackknife analysis of the tree robustness. Application in the RAPD analysis of the genus Frenkelia, Folia Biol., 1999, 45, 97–99.
35. Rademacher P., Weih M. Growth responses of Viscum album to different host species and environmental conditions. Plant Ecology, 2017, 218, 1091–1103.
36. Raftoyannis, Y., Radoglou, K., and Bredemeier, M., Effects of mistletoe infestation on the decline and mortality of Abies cephalonica in Greece, Ann. For. Res., 2015, 58, 1, 55–65. https://doi.org/10.15287/afr.2015.347

37. Sallé A., Brignolas F. Water relations and xylem anatomy of mistletoe–host associations. Tree Physiology, 2020, 40(6), 771–784.
38. Schaller G., Urech K., Grazi G. Viscotoxin composition of the three European subspecies of Viscum album, Planta Med., 1998, 64, 677–678.
39. Schiebel V., Müller J., Bässler C. Host tree traits shape the growth performance of European mistletoe (Viscum album). Trees, 2019, 33(4), 1127–1138. https://doi.org/10.1007/s00468-019-01845-7.
40. Skrypnik L., Maslov D., Kulbachko Y. Remote sensing-based assessment of mistletoe infestation intensity in Salicaceae stands of Eastern Europe. Environmental Monitoring and Assessment, 2020, 192(10), 643. https://doi.org/10.1007/s10661-020-8559-4.
41. Zuber D.Biology and ecology of European mistletoe (Viscum album L.). Botanical Review, 2024, 70(1), 111–157.
42. Zuber, D. and Widmer, A., Genetic evidence for host specificity in the hemi-parasitic Viscum album L. (Viscaceae), Mol. Ecol., 2000, 9, 1069–1073.
43. Zuber, D. and Widmer, A., Phylogeography and host race differentiation in the European mistletoe (Viscum album L.), Mol. Ecol., 2009, 18, 1946–1962. https://doi.org/10.1111/j.1365-294X.2009.04168.x
44. Zuber, D., Biological flora of Central Europe: Viscum album L., Flora, 2004, vol. 199, pp. 181–203.

PHENOLOGICAL DEVELOPMENT AND ORNAMENTAL ASSESSMENT OF *SYRINGA VULGARIS* L. CULTIVARS UNDER FOREST-STEPPE CONDITIONS OF UKRAINE

Melnyk Tetiana
PhD of Biological Sciences, Department of Horticulture and Forestry,Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0002-3839-6018

Trotska Svitlana
PhD in Biological Sciences, Senior Lecturer, Department of Horticulture and Forestry, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0003-2089-5780

Chervona Vika
PhD Student, Department of Horticulture and Forestry, Sumy National Agricultural University, Ukraine
ORCID ID: 0009-0000-2849-2017

The development of modern landscape architecture and urban greening is increasingly associated with the need for continuous optimization and expansion of the assortment of woody and shrub plant species. Contemporary urban environments are characterized by complex and often stressful conditions, including rapid urbanization, climate change, elevated levels of industrial emissions, soil degradation, and increased anthropogenic pressure. These factors significantly alter the ecological framework within which ornamental plants must function, necessitating the selection of species that combine high ornamental value with ecological resilience and adaptability to heterogeneous and often unfavorable growth conditions.

In this context, ornamental shrub species capable of maintaining stable декоративний ефект under variable environmental conditions are of particular importance. Among such species, *Syringa vulgaris* L. occupies a prominent position due to its high ornamental value, ecological plasticity, and relatively low maintenance requirements. This species is widely used in landscape design for parks, gardens, public spaces, and residential areas, where it performs both aesthetic and functional roles. Its tolerance to air pollution and urban stress factors has been noted in studies of urban woody vegetation (Nowak et al., 2006), while its adaptability to different soil conditions makes it suitable for a wide range of landscaping applications.

The genus *Syringa* L., belonging to the family Oleaceae, includes approximately 20–30 species naturally distributed mainly in mountainous regions of Southeastern Europe and Asia (Krüssmann, 1986; Dirr, 2009). Long-term cultivation and breeding have resulted in the development of more than 2000 cultivars, which differ in flowering time, inflorescence morphology, color range, fragrance intensity, and ecological adaptability. This diversity significantly expands the potential for the use of *S. vulgaris* in ornamental horticulture and landscape design and provides a valuable basis for phenological and ecological research.

Phenological development is one of the most informative indicators of plant adaptation to environmental conditions. The timing and sequence of phenological phases-such as bud break, leaf development, flowering, and fruiting-reflect the interaction between genetic traits and climatic factors (Schwartz, 2013). In woody plants, phenology is closely linked to temperature regimes, photoperiod, and water availability, which together regulate the processes of dormancy and active growth.

Under current climate change conditions, phenological studies have gained particular importance. Numerous studies indicate that rising temperatures and changing precipitation patterns lead to shifts in the timing of flowering and other developmental phases (Parmesan & Yohe, 2003; Cleland et al., 2007). Such changes may affect not only plant productivity but also the stability of декоративних насаджень and their ecological functions in urban environments.

For the Forest-Steppe zone of Ukraine, phenological research is especially relevant due to the transitional nature of this region and the variability of climatic conditions. Fluctuations in spring temperatures, late frosts, and uneven precipitation distribution may significantly influence the development of ornamental plants. Under such conditions, cultivar-specific responses become particularly important, as even small differences in biological characteristics can lead to substantial variation in flowering time, duration of декоративного ефекту, and overall plant performance.

Despite the widespread use of *S.vulgaris* in landscaping, the phenological behavior and adaptive capacity of its cultivars remain insufficiently studied at the regional level, particularly in the northeastern Forest-Steppe of Ukraine. Most existing studies focus on general biological or breeding aspects, whereas detailed field-based analyses under specific environmental conditions are limited. This highlights the need for comprehensive research aimed at clarifying seasonal development patterns, evaluating ornamental value, and determining the adaptive potential of S. vulgaris cultivars under local conditions.

The aim of this study is to investigate the peculiarities of the main phenological phases and to assess the ornamental value of *S. vulgaris* cultivars under the conditions of the Forest-Steppe zone of Ukraine.

To achieve this aim, the following objectives were defined:

– to generalize scientific literature on the biological and ornamental characteristics of species and cultivars of the genus *Syringa* L.;

– to conduct phenological observations of the main developmental phases of selected cultivars under regional climatic conditions;

– to analyze phenological and ornamental indicators and determine the prospects for the use of these cultivars in landscaping systems.

Materials and Methods. The research was conducted under the conditions of the northeastern Forest-Steppe zone of Ukraine, which is characterized by moderately continental climatic conditions with relatively warm summers and moderately cold winters. The regional climate is generally favorable for the cultivation of ornamental woody plants; however, fluctuations in temperature and irregular precipitation during the growing season may significantly influence the timing and duration of phenological phases.

The object of the study was *S. vulgaris* L., represented by two cultivars, including the typical species form and the ornamental cultivar 'Ludwig Spaeth'. These cultivars were selected due to their widespread use in landscaping and their distinct ornamental characteristics, which made it possible to assess variability in phenological development and decorative performance under local environmental conditions.

Phenological observations were carried out during the growing season in accordance with generally accepted methods of phenological research. The study focused on recording the timing and duration of the main developmental phases of plants, including bud swelling, bud break, leaf unfolding, formation of flower buds, onset and peak of flowering, end of flowering, and completion of vegetation. The onset of each phenological phase was determined visually based on clearly expressed morphological indicators, ensuring the consistency and reliability of observations.

Special attention was paid to the assessment of ornamental value, particularly during the flowering period, which represents the peak of decorative expression in *S. vulgaris*. The evaluation included the intensity and duration of flowering, color characteristics of inflorescences, uniformity of flowering, and the overall visual effect of plants in landscape compositions. The seasonal dynamics of ornamental attractiveness were analyzed in order to determine the periods of maximum decorative value and the stability of these characteristics under the conditions of the Forest-Steppe zone.

The collected data were subjected to office-based processing, systematization, and statistical analysis. Comparative evaluation of the studied cultivars was carried out to identify differences in phenological behavior and ornamental performance. The interpretation of results was performed taking into account both the biological characteristics of the cultivars and the influence of environmental factors typical for the northeastern Forest-Steppe of Ukraine.

Results. In Ukraine, ***S. vulgaris*** is represented by a considerable cultivar diversity; however, only 21 cultivars are officially included in the State Register of Plant Varieties Suitable for Dissemination in Ukraine, which are recommended for cultivation in different natural and climatic zones of the country (Belorusets et al., 1990; Mordan, Melnyk, 2025). This list includes cultivars of both domestic and foreign breeding, characterized by high ornamental value, adaptability to climatic conditions, stability of flowering, and suitability for various purposes, including ornamental use, landscaping, and cut-flower production (Table 1). At the same time, the actual assortment of *S. vulgaris* cultivars available for commercial and amateur horticulture is significantly broader.

Particularly valuable is the collection fund of the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, which currently represents one of the largest S. vulgaris collections in Europe. The collection includes 21 natural species out of approximately 28 known in the world flora, as well as more than 90 ornamental hybrids developed through the breeding program of the Botanical Garden (Kokhno, 2002). Such a representative gene pool provides extensive opportunities for breeding research, evaluation of cultivar adaptability under Forest-Steppe conditions, and the development of new promising cultivars. Owing to this, Ukrainian cultivars are regularly included in international catalogs and attract the attention of specialists in ornamental horticulture.

The cultivars of *S. vulgaris* recommended for Ukraine are distributed according to growing zones: Steppe, Forest-Steppe, and Polissia. This approach takes into account differences in temperature regimes, moisture availability, and plant resistance to critical climatic conditions, which allows for the proper selection of cultivar assortments for specific territories. A significant proportion of cultivars is characterized by ecological plasticity, enabling their cultivation in several natural zones due to their high frost resistance and ability to adapt to contrasting environmental conditions.

Table 1. List of *Syringa vulgaris* cultivars included in the State Register of Plant Varieties Suitable for Dissemination in Ukraine

Cultivar name *Syringa vulgaris*	Recommended zone	Direction of use*
′Bohdan Khmelnytskyi′	Forest-Steppe, Polissia	O, C, L
′Vohni Donetska′	Steppe, Forest-Steppe, Polissia	L, C.
′Vohni Donbasu′	Forest-Steppe, Polissia	O, C, L
′Hortensiia′	Forest-Steppe, Polissia	O, L, C
′Den Peremohy′	Forest-Steppe, Polissia	O, L, C
′Donetski Zori′	Steppe, Forest-Steppe, Polissia	L, C
′Donetskyi Suvenir′	Steppe, Forest-Steppe, Polissia	L, C
′Dochka Tamara	Forest-Steppe, Polissia	O, L, C
′Krasavytsia Moskvy′	Forest-Steppe, Polissia	O, L, C
′Lilova Piramida′	Forest-Steppe, Polissia	O, L, C
′Lesia Ukrainka′	Forest-Steppe, Polissia	O, C, L
′Mechta′	Forest-Steppe, Polissia	O, L, C
′Moskovskyi Universytet′	Forest-Steppe, Polissia	O, L, C
′Professor V.I. Chopyk′	Steppe	L.
′Professor M.L. Reva′	Steppe, Forest-Steppe, Polissia	L, C
′Professor O.L. Lypa′	Steppe, Forest-Steppe, Polissia	L., C.
′Reomor′	Forest-Steppe, Polissia	O, L, C
′Snizhnyi Kom′	Forest-Steppe, Polissia	O, L, C
′Taras Bulba′	Forest-Steppe, Polissia	O, C, L
′Charivnist′	Forest-Steppe, Steppe	L

Note: *Direction of use: Ornamental (O), Cut (C), Landscaping (L).*

The functional purpose of cultivars is also of considerable importance. Ornamental cultivars are used for the creation of accent compositions, solitary plantings, and collection displays. Cut-flower cultivars are distinguished by dense, large inflorescences and a pronounced fragrance, making them suitable for floral arrangements. Landscaping cultivars are characterized by increased resistance to urban conditions, including air pollution, soil compaction, and irregular moisture supply, which makes them particularly valuable for use in urban environments of Ukraine, including within the Forest-Steppe zone.

A detailed list of officially recommended cultivars of S. vulgaris is presented in Table 3.1, indicating the recommended natural zones of cultivation and directions of use. Among the most well-known and widely distributed cultivars are ′Bohdan Khmelnytskyi′, ′Den Peremohy′, ′Krasavytsia Moskvy′, ′Lesia Ukrainka′, ′Lilova Piramida′, ′Taras Bulba′, ′Moskovskyi Universytet′, ′Snizhnyi Kom′, ′Vohni Donbasu′, and ′Donetski Zori′. These cultivars are characterized by stable and abundant flowering, a wide range of color variations, and good establishment under moderately continental climatic conditions.

Thus, the cultivar diversity of *S. vulgaris* in Ukraine is extremely broad and includes officially registered, collection, and experimental cultivars. The combination of a rich gene pool, established breeding traditions, and the natural adaptability of the species provides a solid basis for studying the phenological characteristics of cultivars, their comparative ornamental value, and their resistance to the conditions of the Forest-Steppe zone, which is particularly important in the context of regional research.

Peculiarities of the Progression of the main phenological phases of *S. vulgaris*. The progression of phenological phases in common *S. vulgaris* is formed under the influence of numerous ecological and internal plant factors, which determine the rhythm of seasonal development, the timing of the onset of vegetation and flowering, the duration of generative processes, as well as the overall ornamental value of plants. The most significant factors include climatic conditions, cultivar characteristics, soil properties of the growing site, the condition of the root system, water regime, level of nutrient supply, and anthropogenic impact. All these factors act in a complex manner; therefore, the interaction of their effects often determines the individual phenological rhythm of each cultivar under specific environmental conditions.

Climatic conditions are the leading factor determining the timing of the main phenological phases. Temperature influences the rate of sap flow initiation, the timing of bud swelling, and the development of generative organs. A prolonged period of low temperatures in winter is necessary to complete physiological dormancy and to ensure the formation of fully developed buds. In the Forest-Steppe zone of Ukraine, the increase in spring temperatures usually stimulates an early onset of *S. vulgaris* vegetation; however, sharp drops in temperature or frosts during the budding period can suppress the development of inflorescences, deform panicles, or reduce the duration of flowering. The amount of effective temperatures (the sum of active temperatures) determines the rate of development of phenological phases; therefore, in years with warmer springs, early cultivars begin flowering several days earlier than in years with slower warming. Air humidity and precipitation also significantly affect *S. vulgaris*: insufficient soil moisture or prolonged spring drought may lead to a reduction in inflorescence size, suppression of shoot growth, and shortening of the mass flowering phase.

Soil conditions determine the development of the root system and the overall physiological activity of plants. *S. vulgaris* grows best on structured, fertile, moderately moist soils with a pH close to neutral. Acidic soils slow down nutrient uptake and disrupt the synthesis of physiologically active substances, which reduces the quality of inflorescences and may shift flowering periods.

Excessive moisture and water stagnation in the root zone block root respiration and lead to metabolic disturbances, which negatively affect the development of generative organs. Conversely, optimal nutritional conditions, sufficient organic matter content, and favorable soil structure ensure active formation of flower buds and stability of phenological processes.

Cultivar and genetic characteristics also play an important role. Different *S. vulgaris* cultivars exhibit distinct rhythms of seasonal development, which is manifested in the timing of bud swelling, the rate of bud opening, and the duration of budding and flowering. Plant responses to temperature fluctuations and drought are also genetically determined. Early cultivars are capable of activation at lower temperature sums, whereas late cultivars require longer spring warming. At the same time, the degree of sensitivity to spring frosts is cultivar-specific: some cultivars better preserve generative organs under stress conditions, while others respond by reducing or completely losing inflorescences.

Management practices and anthropogenic impact also significantly determine the seasonal development of plants. The presence of formative and sanitary pruning affects the number and vigor of annual shoots and, consequently, the formation of flower buds. Improper pruning, especially excessive removal of shoots in summer or autumn, may disrupt the annual development cycle and shift flowering phases to later periods or reduce their intensity. Adequate light conditions are a key prerequisite for the formation of fully developed generative structures: shading causes shoot elongation, reduces the number of inflorescences, and leads to shifts in phenological phases.

Biotic factors, such as disease infection and pest damage, affect the physiological state of plants and may alter the intensity of phenological phase progression. Leaf damage reduces photosynthetic productivity and limits the plant's ability to form flower buds. Diseases of the root system or trunk lead to delayed bud swelling, weak budding, and uneven flowering. Thus, the phenological development of *S. vulgaris* is the result of a complex interaction of external and internal factors.

Under the conditions of the Forest-Steppe zone of Ukraine, the most important factors are the temperature regime of the spring period, moisture availability, cultivar characteristics, and plant management practices. The study of the influence of these factors makes it possible to assess the prospects of individual cultivars and to form the most optimal assortment for ornamental landscaping and stable seasonal flowering.

Phenological observations of *S. vulgaris* plants (T-21) and the cultivar 'Ludwig Spaeth' (T-19) made it possible to trace the patterns of seasonal development and to identify cultivar-specific differences that manifest at different stages of the vegetation cycle. The onset of vegetation in both plants was synchronous: the buds became lighter, increased in volume, and their surface lost the winter dullness and acquired a characteristic gloss (Fig. 1.A).

The described feature indicates the activation of cellular processes in the buds and the transition of the plant from a state of deep winter dormancy to pre-vegetative development.

Further development was accompanied by bud break; however, it was at this stage that the first differences in timing were observed. Plants of T-19 began the separation of protective bud scales earlier, which indicates either a faster accumulation of effective temperatures or a higher sensitivity to changes in photoperiod. T-21 entered this phase approximately five days later (Fig. 1.Б).

The photographs clearly demonstrate the exposure of the apical meristem and the initial growth of young tissues, which is characteristic of early spring differentiation.

At the budding stage, the situation changed: T-21 formed flower primordia earlier than T-19. Figure 1.B shows a fully opened bud with a visible generative primordium, which is a characteristic feature of the transition to intensive inflorescence development. At this time, T-19 still exhibited partial covering of the primordium by bud scales. This confirms cultivar-specific differences in the rate of development, which are likely associated with genetic characteristics and different responses to spring temperature fluctuations.

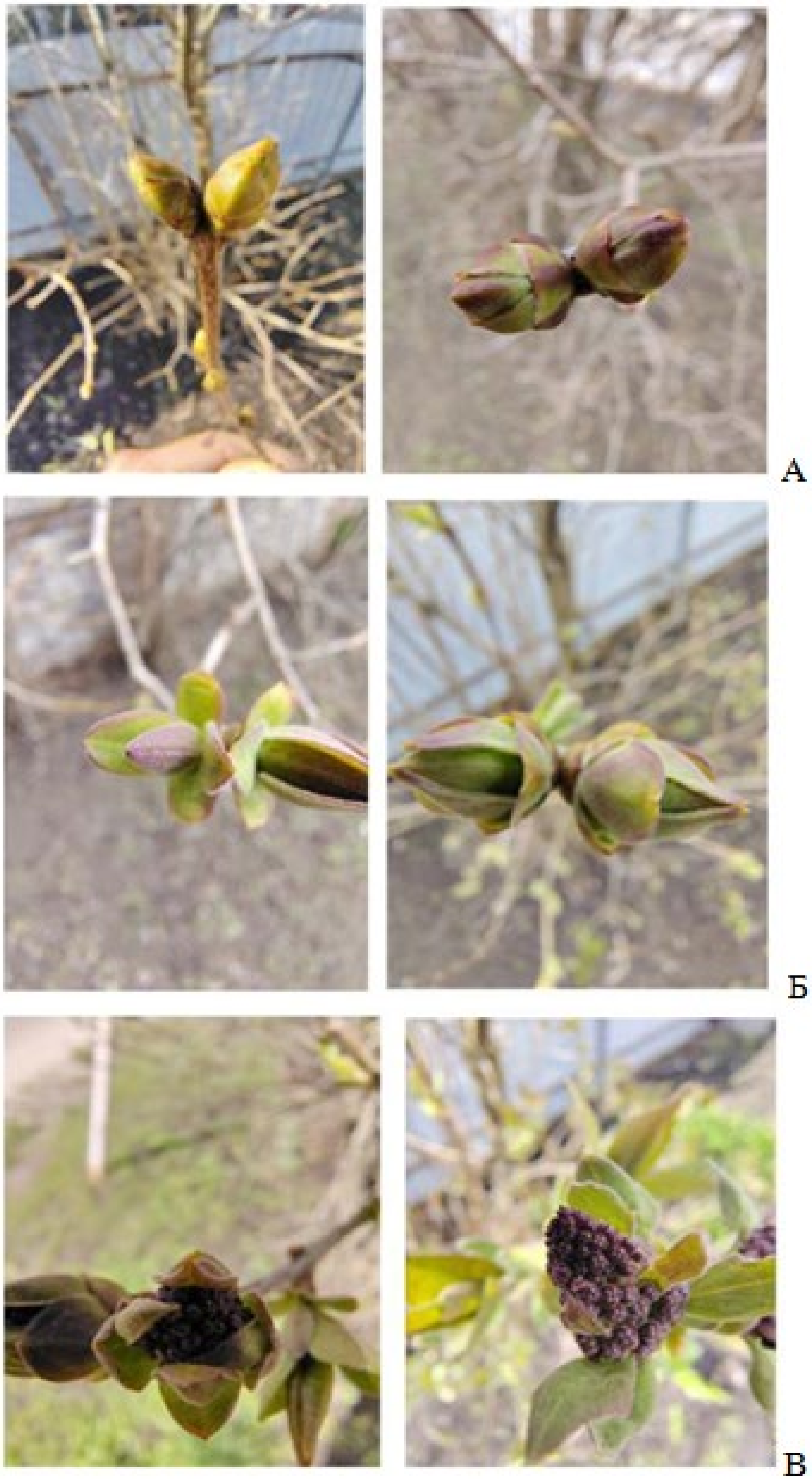


Figure 1. Main stages of early phenological development of Syringa vulgaris: A – Initial stage of bud swelling in T-19 and T-21 at the beginning of March; a lighter color and increased turgor are clearly observed; B – Beginning of the opening of protective bud scales in T-19 and bud break in T-21, occurring with a delay of approximately 5 days; C – Formation of flower buds in T-21: fully opened bud scales and appearance of floral primordia (photo by A. Mordan).

Further elongation and formation of inflorescences proceeded in a regular manner. In the control plants, long, upright inflorescences reaching up to 30 cm were observed, with two or three pairs of racemose branches; in T-21, the inflorescences were more compact, up to 20 cm in length, but distinctly conical in shape. Differences between the plants were also manifested in flower size: T-19 had larger flowers of a purplish-red coloration, whereas the cultivar plants were characterized by smaller, *S. vulgaris* – violet flowers, which corresponds to the typical characteristics of the cultivar ′Ludwig Spaeth′.

Flowering first occurred in T-21, and approximately five days later T-19 also entered the flowering phase. Figure 2 illustrates this stage, demonstrating the higher early spring activity of the cultivar.

Figure 2. Full flowering phase (peak flowering stage) (photo by A. Mordan).

Following the completion of flowering, plants transitioned to the fruiting stage.

Both variants formed glossy, elongated, ovate capsules, which gradually matured over an extended period. The photographs show their initial green stage as well as their subsequent drying at the end of summer. Both plants completed fruiting almost simultaneously, at the end of August (Fig. 3).

After the full opening of the capsules, the plants gradually entered the stage of vegetation decline. In autumn, differences in leaf coloration became evident. In T-19, the leaves acquired a dark green or purplish-red оттенок, retained crown density, and exhibited resistance to premature leaf fall. In contrast, T-21 was characterized by a light yellow coloration, sometimes with purple shades, and a more sparse crown structure. Differences in the nature of autumn coloration and the rate of leaf fall are shown in Figure 4.

Figure 3. Completion of the fruiting stage (photo by A. Mordan).

Figure 4. Characteristic features of autumn coloration and the rate of leaf fall (photo by A. Mordan).

At the beginning of November, T-21 had almost completely shed its leaves, whereas T-19 still partially retained them, which indicates a longer duration of active physiological processes (Fig. 5).

By the end of November, both plants had completely lost their leaves, and the buds had acquired a darker coloration and became more compact, as shown in Figure 6.

In mid-December, the plants were in a state of complete dormancy, which represents the natural completion of the annual development cycle. This is confirmed by the photographs in Figure 7, where dense, dark buds fully adapted to winter conditions can be observed.

Figure 5. Completion of the leaf fall stage in the studied samples (photo by A. Mordan).

Figure 6. Preparation for winter dormancy: leaf shedding and bud compaction (photo by A. Mordan).

A comparison of the phenological phases of T-19 and T-21 revealed a number of significant cultivar differences that have practical importance for ornamental horticulture, landscape design, and further breeding research.

The onset of vegetation in both plants was synchronous, indicating a similar response to spring climatic conditions. However, at the stage of bud break, T-19 exhibited a faster response to thermal stimuli, whereas generative processes, on the contrary, intensified earlier in T-21. This indicates a differentiation in the rates of development of vegetative and generative organs depending on cultivar characteristics. The earlier budding and flowering of T-21 confirm literature data that the cultivar 'Ludwig Spaeth' is characterized by high stability of flowering onset and moderate sensitivity to weather fluctuations.

Figure 7. Plants in a state of complete dormancy (photo by A. Mordan).

The characteristics of inflorescences also differed significantly between the variants. The control plants formed larger and more spreading inflorescences, which is a typical feature of wild-type *S. vulgaris*, whereas the cultivar plants produced more compact but brighter panicles, which enhances their ornamental value in urban plantings and private gardens. Differences in flower size indicate biological characteristics of the cultivar and are likely associated with genetically determined differences in the size of the perianth.

The fruiting phases in T-19 and T-21 coincided, demonstrating a leveling of developmental rates under conditions of a stable summer photoperiod and sufficient thermal resources. The autumn phase of vegetation revealed significant differences in leaf coloration, the rate of leaf senescence, and the timing of leaf fall. T-21 transitioned to the autumn state more rapidly, which may be associated with its cultivar-specific nature, implying a shorter period of active growth. In contrast, T-19 retained green foliage for a longer time, indicating a longer duration of physiological activity.

After the completion of field phenological observations, all obtained data were systematized and recorded in a generalized table. The timing of the main phenological phases was determined in accordance with the methodology for the examination of varieties of ornamental, medicinal, and aromatic plants [18, 20]. The obtained results are presented in the table.

In Table 3.2, clear differences in the timing of the main phenological phases between *S. vulgaris* variants T-21 and T-19 can be observed. For variant T-21, the onset of vegetation was recorded on March 9, bud break on March 25, the budding phase lasted from April 9 to April 23, flowering occurred from April 23 to May 22, fruiting from April 25 to August 26, and the completion of vegetation on December 12.

The T-19 variant was characterized by a different dynamic of phenological phase progression: the onset of vegetation also occurred on March 9; however, bud break was observed earlier, on March 21. The budding phase lasted from April 12 to April 28, flowering from April 28 to May 27, fruiting from May 30 to August 26, and the completion of vegetation coincided with that of T-21 and also occurred on December 12.

The identified differences in the rate of plant development indicate cultivar-specific and individual features of the response of *S. vulgaris* to environmental conditions, which determine different rates of progression of individual stages of organogenesis. For better visualization of the dynamics of phenological development, a calendar chart of the progression of phenological phases was constructed (Fig. 8), which allows a clear comparison of the duration and sequence of developmental phases in variants T-21 and T-19.

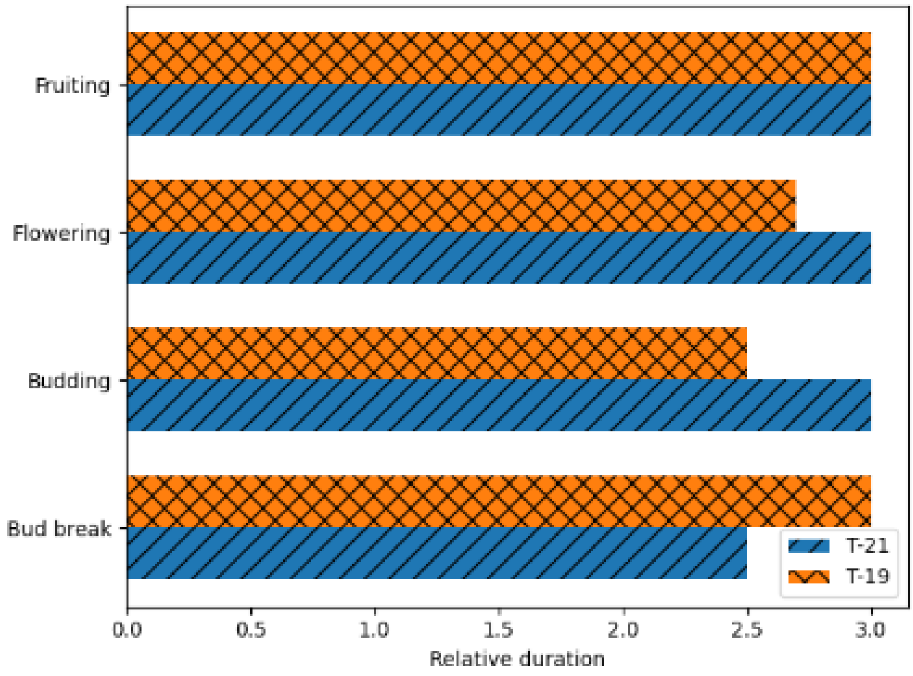


Figure 8. Comparison of the rate of progression of phenological phases in the studied samples of S. vulgaris.

In general, graphical and tabular comparison indicates that T-21 is an early-flowering variant with a more intensive generative phase, whereas T-19 demonstrates a more stable and prolonged vegetation period. Such differences are important for the selection of cultivars in ornamental plantings: T-21 is advisable for use where early and ярке flowering is required, whereas T-19 ensures a longer decorative effect in park-type green spaces.

Evaluation of the Ornamental Value of *Syringa vulgaris.* The ornamental value of *S. vulgaris* is assessed comprehensively, taking into account morphological, phenological, physiological, and landscape-decorative parameters that determine the visual expressiveness of the plant throughout the growing season. The analysis of ornamental value involves the study of crown characteristics, leaves, shoots, inflorescences, and the overall compositional role of the cultivar in the landscape environment.

One of the key criteria is the shape and architectonics of the crown, since the silhouette of *S. vulgaris* in both leafless and foliated states determines its decorative expressiveness throughout the year. Parameters such as plant height, crown diameter, symmetry, density, and the ability to maintain a stable shape under pruning are evaluated. The leaf apparatus is assessed according to size, shape, intensity of coloration, leaf density on shoots, resistance to sunburn, and resistance to premature drying. An important indicator is also leaf resistance to biotic stresses, including fungal and bacterial diseases, which may reduce the overall ornamental value of the plant (M.M. Gryshko…, 2020; Potapskyi et al., 2021).

The most important group of criteria determining the ornamental value of *S. vulgaris* consists of flowering characteristics. These include the timing of budding, duration of flowering, uniformity of flower opening within the inflorescence, and synchronization of flowering among different plants of the same cultivar. The number of inflorescences per shoot and per plant, their length, width, density, shape, as well as the direction and degree of branching are also determined. Special attention is paid to flower coloration, which may change at different stages of development - from bud to full bloom and to the end of flowering. Color saturation, uniformity, presence of gradients, contrast between the outer and inner sides of petals, and resistance of coloration to solar radiation are analyzed. The texture of flowers is also taken into account, as simple, double, and semi-double forms have different decorative potential in park compositions.

A separate indicator of ornamental value is flower fragrance, since *S. vulgaris* is distinguished by a wide range of aromatic profiles. The intensity, persistence, and qualitative characteristics of the fragrance are important when using cultivars in areas of mass visitation. In landscape practice, resistance of S. vulgaris to urban environmental conditions is of great importance, including tolerance to air pollution, dust resistance, resistance to compacted soils, and the ability to withstand periods of temporary drought. These indicators directly affect ornamental value, since physiological stress is often reflected in leaf quality, the number of inflorescences, and the duration of flowering.

The phenological analysis of ornamental value includes the study of seasonal dynamics. The timing of leaf emergence, the beginning and end of budding, flowering phases, fruit formation, and the completion of vegetation are recorded. It is important to assess their stability over years, which makes it possible to determine the level of cultivar adaptability to climatic conditions. A comprehensive evaluation of ornamental value is supplemented by morphometric measurements, which allow comparison of cultivars and their ranking. Such indicators include inflorescence length, flower diameter, number of flowers per inflorescence, average number of inflorescences per shoot, and other quantitative criteria.

The final stage of ornamental analysis is the evaluation of the compositional role of the cultivar. The ability of *S. vulgaris* to create accent points in space, the harmony of combinations with other woody and herbaceous plants, the suitability of the cultivar for specific landscaping styles, and the seasonal expressiveness of compositions are taken into account. Based on the collected data, an integral scoring assessment of ornamental value is carried out, which makes it possible to identify the most promising cultivars for use in landscaping public spaces, squares, parks, and private areas.

The ornamental value of *S. vulgaris* has long been the subject of scientific interest in Ukraine and European countries, as this species belongs to the most widespread and highly valued ornamental shrubs in green plantings. In modern research, ornamental qualities are considered in close connection with morphological, phenological, breeding, and physiological-biological characteristics, as well as with plant adaptability to various urban environmental conditions.

Ukrainian researchers, particularly scientists of the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, pay special attention to the comprehensive evaluation of S. vulgaris cultivars. In the publications of Volodymyr Horb, morphometric approaches to the study of ornamental characteristics are described, including crown shape and density, branching intensity, leaf coloration and texture, as well as the structure, size, and architecture of inflorescences. The author emphasizes the necessity of evaluating new hybrids and cultivars in comparison with reference collections, which allows determination of their true ornamental value and compliance with modern landscaping requirements.

At the M.M. Gryshko National Botanical Garden, one of the largest *S. vulgaris* collections in Europe has been established, containing dozens of cultivars and hybrids of both Ukrainian and international breeding. This creates a unique basis for studying the variability of ornamental traits, flowering timing, resistance to adverse conditions, and the potential use of different cultivars in urban landscaping.

significant contribution to the study of ornamental qualities of *S. vulgaris* has also been made in the dendrological park “Oleksandriia” of the National Academy of Sciences of Ukraine, where a comprehensive inventory and optimization of the “Syringarium” exposition has recently been carried out. These studies focus on the age structure of plantings, soil condition, plant vitality, **the prospects of individual cultivars**, and the need to restore the collection to enhance its decorative effect. Such research demonstrates the importance of a systematic approach that combines morphological observations with the analysis of growing conditions.

European scientific literature presents a wide range of studies aimed at evaluating the ornamental value of *S. vulgaris* based on phenological, biological, and genetic traits. In Poland, long-term studies of flowering phenology of various species of the genus *Syringa* have been conducted in botanical gardens in Poznań and Warsaw. In the works of M. Szwed and W. Antkowiak, the timing of budding, dynamics of flower opening, duration, and peaks of flowering are analyzed in detail, which makes it possible to determine the suitability of different cultivars for use in public spaces and urban green areas. These phenological indicators are considered integral criteria of ornamental value, as they ensure the harmony of seasonal perception of plantings (Laptiev, 2001).

An important direction of scientific research related to the preservation of ornamental qualities of cut inflorescences is represented by a group of Polish researchers studying post-harvest physiology of S. vulgaris flowers. Their results show that growing conditions, water regime, and the use of preservatives and antiseptic substances significantly affect the duration of decorative appearance of flowers in floral compositions. These studies emphasize that the ornamental value of *S. vulgaris* is important not only in landscaping but also in the floricultural sector.

In the countries of Northern Europe, attention is focused on historical, genetic, and morphological aspects of *S. vulgaris* ornamental value. In Finland, inventories of old cultivars of *S. vulgaris* planted in cultural landscapes of the 18th–19th centuries have been conducted. Studies by Lindén and Korpelainen show that many old cultivars retain unique ornamental traits, such as complex structure of double flowers, rare petal shades, particularly strong fragrance, or prolonged flowering. Researchers use genetic profiling methods to identify old plants, determine their origin, and preserve valuable genotypes. The combination of morphological and molecular-genetic methods opens new opportunities for studying ornamental properties and restoring lost historical cultivars (Kyienko, Matus, Tkachyk, 2016)

In addition to European studies, significant contributions to the study of the genus *Syringa* have been made by Chinese researchers, who focus on species diversity, morphological traits, and phytochemical properties. Their review publications provide data on ecological growth conditions and the ornamental potential of many species, which may be useful for breeding programs and expanding the ornamental assortment.

The general analysis of scientific studies shows that the ornamental value of *S. vulgaris* is evaluated comprehensively, including crown architectonics, leaf quality, inflorescence characteristics, flower coloration and fragrance, duration and intensity of flowering, resistance to diseases, and adaptability to urban conditions. An important factor is phenological stability, which determines the predictability of decorative effect in different years. Modern studies increasingly combine classical dendrological methods with genetic analysis, phytopathological assessments, and approaches of urban landscape design.

Thus, scientific works of Ukrainian and European researchers form a broad theoretical and practical basis for analyzing the ornamental value of *S. vulgaris*. The generalization of these studies allows the formation of modern approaches to cultivar evaluation, substantiation of the selection of ornamental assortments for different types of green plantings, and determination of priority directions for breeding and introduction of this species.

During the phenological research, the ornamental value of plants was also assessed, as this indicator is one of the key criteria for the suitability of *S. vulgaris* for use in urban landscaping (Schwartz M.D., 2013). Under conditions of an urbanized environment, ornamental characteristics are an important factor in shaping an attractive urban landscape image, which necessitates a comprehensive evaluation of decorative traits throughout the entire growing season. Taking into account the gradual decline in ornamental value after flowering, a general assessment of decorative parameters at different stages of vegetation was carried out under the conditions of the Sumy region. The evaluation was conducted in accordance with the methodology for the examination of ornamental plant varieties for suitability for dissemination in Ukraine. Ornamental value was assessed using a four-point scale, while the degree of flowering and the level of foliage were evaluated using a five-point scale. The results of the assessment are presented in Table 3.

Table 2. Evaluation of the ornamental value of the studied *Syringa vulgaris* samples

Variant	Trait (score)	Foliage density	Flowering	Growth habit	Total score
S. vulgaris (control)	-	5	4	3	12
S. vulgaris 'Ludwig Spaeth' (T-19)	-	5	5	4	14

The analysis of the obtained data indicates that the cultivars differ in a complex of ornamental traits. The cultivar ‘Ludwig Spaeth’ (T-19) demonstrated the highest total ornamental score, which can be explained by more intensive and prolonged flowering, as well as a high level of foliage density. At the same time, the common *S. vulgaris* in the control variant was also characterized by sufficiently high ornamental properties, confirming its suitability for widespread use in urban landscaping.

For a more in-depth analysis, a decorative calendar was developed, integrating the results of phenological observations and the scoring evaluation of ornamental traits (Fig. 9). The obtained data make it possible to trace the seasonal dynamics of ornamental value and to assess the periods of maximum plant expressiveness.

The decorative calendar shows that *S. vulgaris* exhibits its maximum aesthetic qualities in the third month of spring, during the period of mass flowering. It is during this period that the plants reach the peak of ornamental value due to the abundant formation of inflorescences, the intense purple coloration (in the cultivar 'Ludwig Spaeth'), and the harmonious combination of flowers with bright green foliage.

After flowering, the ornamental value slightly decreases; however, *S. vulgaris* retains an attractive appearance due to its dense, compact, and well-foliated crown of dark green color. The leaves remain on the plants until the second month of autumn, after which decreasing temperatures cause their gradual shedding. During the winter period, ornamental value decreases to a minimum level, although the crown structure retains a certain plastic expressiveness.

Thus, the results of the study confirm that *Syringa vulgaris* and its cultivar 'Ludwig Spaeth' are highly ornamental plants with pronounced seasonal dynamics. Despite the decline in ornamental value after the completion of flowering, during a long period of summer and until mid-autumn they remain important elements of urban landscaping due to their dense crown, stable foliage, and overall bioaesthetic attractiveness.

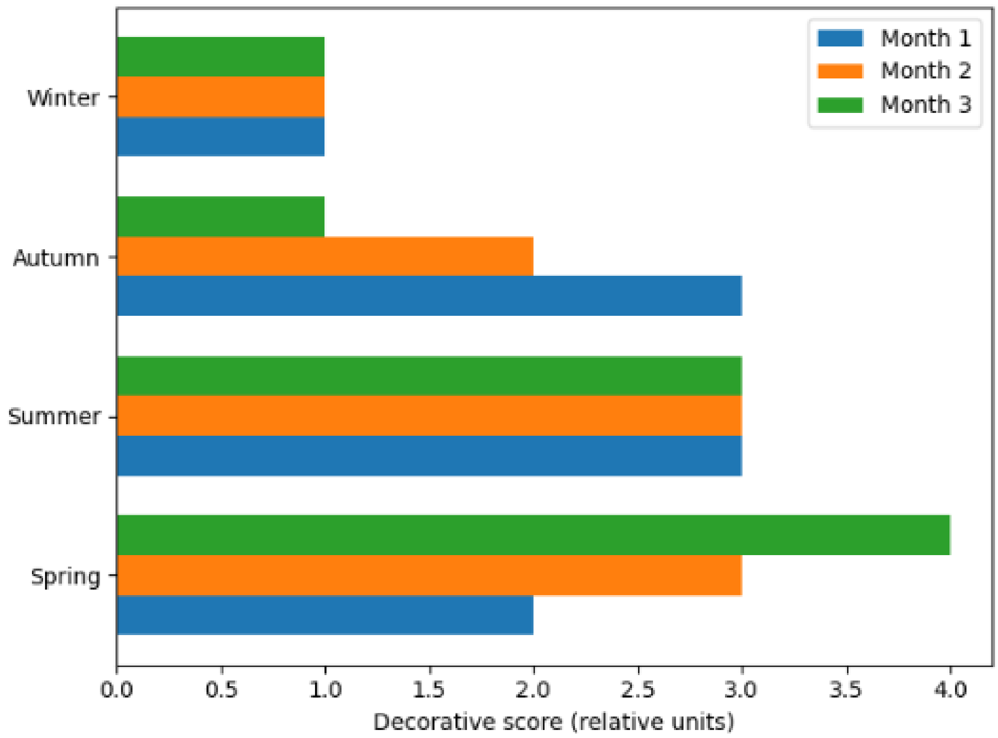


Figure 9. Ornamental value of the studied S. vulgaris samples across the seasons of the year.

Discussion. The obtained results confirm that the phenological development of ***S. vulgaris*** cultivars under the conditions of the Forest-Steppe zone of Ukraine is determined by a complex interaction of climatic factors and genetically determined cultivar characteristics. The synchronous onset of vegetation in both studied variants (T-19 and T-21) indicates a similar response of plants to the accumulation of effective temperatures at the end of the winter period, which is consistent with general patterns of phenological activation in temperate woody species.

At the same time, the revealed differences in the timing of subsequent phenological phases demonstrate the importance of genotype-specific regulation of developmental processes. In particular, the earlier bud break observed in T-19 suggests a higher sensitivity to thermal stimuli or a lower threshold of temperature accumulation required for growth activation. Conversely, the earlier initiation of budding and flowering in T-21 indicates a more rapid transition to the generative stage, which may be associated with cultivar-specific features of organogenesis and internal physiological regulation.

Such differentiation between vegetative and generative development rates confirms that the phenological behavior of *S. vulgaris* cultivars cannot be explained solely by external environmental factors. Instead, it reflects the interaction between climatic conditions and genetically determined adaptive strategies. This is particularly important for ornamental horticulture, where the timing and duration of flowering are key indicators of ornamental value.

The influence of climatic conditions, especially temperature fluctuations during the spring period, was clearly reflected in the dynamics of phenological phases. The observed shifts in the timing of bud break and flowering between cultivars correspond to established concepts regarding the role of accumulated heat units in regulating plant development. At the same time, the sensitivity of generative organs to spring frosts highlights the vulnerability of flowering processes and emphasizes the importance of selecting cultivars with higher stress tolerance for urban and landscape plantings.

The results of the study also indicate that the duration of the flowering period and the stability of ornamental traits are closely related to cultivar characteristics. The cultivar 'Ludwig Spaethё demonstrated more intensive and expressive flowering, which directly influenced its higher ornamental score. This finding aligns with the general understanding that the ornamental value of S. vulgaris is primarily determined by the abundance, uniformity, and visual expressiveness of inflorescences.

An important aspect revealed in the study is the difference in the duration of the vegetation period. The longer retention of foliage in T-19 indicates a prolonged period of physiological activity, which may be associated with a more efficient photosynthetic apparatus and greater resistance to environmental stress factors. In contrast, the earlier transition of T-21 to autumn senescence suggests a shorter period of active growth, which may be advantageous under certain climatic conditions but reduces the duration of the ornamental effect outside the flowering phase.

The coincidence of fruiting phases in both cultivars suggests that under stable summer conditions, characterized by sufficient thermal resources and a relatively constant photoperiod, differences in developmental rates tend to level off. This indicates that environmental conditions during the summer period have a stabilizing effect on phenological processes.

The comprehensive assessment of ornamental value confirmed that both studied variants possess high ornamental potential, although with different patterns of seasonal expression. The cultivar 'Ludwig Spaeth' is characterized by a more pronounced and prolonged decorative effect due to intensive flowering and stable foliage, whereas the control form of *S. vulgaris* demonstrates balanced characteristics and reliable adaptability.

From a practical perspective, the identified differences between cultivars have important implications for landscape design. The earlier flowering of T-21 makes it suitable for creating early-season accents in plant compositions, while the prolonged vegetation and stable ornamental performance of T-19 make it more appropriate for plantings where a long-lasting visual effect is required. The combination of such cultivars in landscaping schemes allows for the extension of the overall decorative period and increases the variability of visual effects in green spaces.

Thus, the results obtained not only expand the understanding of the phenological behavior of *S. vulgaris* cultivars under the conditions of the Forest-Steppe zone of Ukraine but also provide a scientific basis for their rational use in ornamental horticulture and urban landscaping.

Conclusions. 1. The cultivar diversity of *Syringa vulgaris* in Ukraine is extensive and scientifically substantiated. The State Register of Plant Varieties Suitable for Dissemination in Ukraine includes 21 cultivars recommended for cultivation in the Steppe, Forest-Steppe, and Polissia zones. The presence of a substantial collection fund, particularly in the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, where 21 species and more than 90 ornamental hybrids are maintained, provides a reliable genetic basis for further breeding and introduction studies, as well as for expanding the assortment of plants used in landscaping.

2. The phenological development of *Syringa vulgaris* under the conditions of the Forest-Steppe zone of Ukraine is characterized by pronounced cultivar-specific differences against the background of overall stability of the annual growth cycle. For both studied variants (T-19 and T-21), a synchronous onset of vegetation was observed; however, the timing of bud break, budding, and flowering differed significantly. The cultivar 'Ludwig Spaeth' (T-19) is characterized by earlier and more intensive flowering, whereas T-21 demonstrates phenological phases that are slightly shifted in time but more balanced in duration. These results indicate differences in the rate of organogenesis under identical environmental conditions.

3. The ornamental characteristics of the studied *Syringa vulgaris* samples were evaluated as high, with a clear advantage of the cultivar 'Ludwig Spaeth'. According to the scoring assessment, this cultivar (T-19) achieved the highest total score (14 points) due to the combination of abundant, bright, and prolonged flowering, high foliage density, and a well-defined crown habit. The control variant of *S. vulgaris* also demonstrated high ornamental properties (12 points), confirming its suitability for widespread application in urban landscaping.

4. The decorative calendar revealed a pronounced seasonal dynamics of ornamental expression. The peak of ornamental value occurs during the period of mass flowering in late spring, when the combination of abundant inflorescences and dense foliage ensures the maximum visual effect. After the flowering period, plants retain a high level of ornamental value due to their dense, well-foliated crowns of dark green coloration, which maintain the aesthetic appeal of plantings until mid-autumn. This feature represents an important advantage for their use in urban green spaces.

5. The results obtained confirm the high potential of Syringa vulgaris and the cultivar ′Ludwig Spaeth′ for landscaping under the conditions of the Forest-Steppe zone of Ukraine. The combination of ecological adaptability, resistance to urban environmental factors, stability of phenological indicators, and high ornamental value provides a strong basis for recommending these forms for use in various types of green plantings, including parks, squares, alleys, and accent compositions, as well as for their further use in breeding and landscape-oriented research.

Acknowledgements. The authors express their sincere gratitude to Andrii Mordan, MSc student, for providing photographic materials used in this study.

REFERENCES

1. Agrarii Razom Information System, (n.d.) Description and characteristics of Syringa vulgaris. Available at: https://agrarii-razom.com.ua/plants/buzok-zvichayniy.
2. Agrarii Razom Information System, (n.d.) Lilac cultivation: features of growing and storage. Available at: https://agrarii-razom.com.ua/culture/buzok.
3. Belorusets E.Sh., Horb V.K., (1990) Lilac. Kyiv: Urozhai, 176 p.
4. Botanical Garden of Sumy State Pedagogical University named after A.S. Makarenko, (n.d.) Available at: https://pgf.sspu.edu.ua.
5. Cleland E.E., Chuine I., Menzel A., Mooney H.A., Schwartz M.D., (2007) Shifting plant phenology in response to global change. Trends in Ecology & Evolution, 22(7), 357–365.
6. Kokhno M.A. (Ed.), (2002) Dendroflora of Ukraine. Wild and cultivated trees and shrubs. Angiosperms. Part I. Kyiv: Vyshcha Shkola, 448 p.
7. Dolhova L.H., Zaitseva I.O., (n.d.) Phenorhythmic patterns of introduced woody plants of the genus Syringa. Bulletin of Dnipropetrovsk University. Biology, Ecology.
8. Dziuba I.M., Zhukovskyi A.I., Zhelezniak M.H., et al. (Eds.), (2016) Encyclopedia of Modern Ukraine. Kyiv: Institute of Encyclopedic Research of NAS of Ukraine. Available at: https://esu.com.ua/article-53581.
9. Horb V.K., (2018) Biological, morphometric and ornamental features of Syringa fauriei Lev. and methods of its use in landscaping. Plant Introduction, (4).
10. Horb V.K., (2002) Growth and development of generatively mature plants of the genus Syringa L. under the conditions of Kyiv. Plant Introduction, (2).
11. Horb V.K., (1989) Lilac in Ukraine. Kyiv: Naukova Dumka, 158 p.
12. Horb V.K., Klymenko Yu.O., Dovhaliuk N.I., (2020) Influence of crown management system on ornamental value and longevity of Syringa vulgaris cultivars. Scientific Bulletin of UNFU, 30(4).
13. Institute of Evolutionary Ecology of NAS of Ukraine, (n.d.) Common lilac. Available at: https://www.ieenas.org/p/buzok-zvichainii.
14. Krüssmann G., (1986) Manual of Cultivated Broad-Leaved Trees and Shrubs. Timber Press.
15. Kyienko Z.B., Matus V.M., Tkachyk S.O., (2016) Methodology for examination of plant varieties (ornamental, medicinal, essential oil and forest) for suitability for dissemination in Ukraine. Vinnytsia: Ukrainian Institute for Plant Variety Examination, 12 p.
16. Laptiev O.O., (2001) Introduction and acclimatization of plants with fundamentals of landscaping. Kyiv: Fitosotsiotsentr, 109 p.
17. M.M. Gryshko National Botanical Garden of NAS of Ukraine, (n.d.) Available at: http://www.nbg.kiev.ua/collections_expositions/index.php?SECTION_ID=192.
18. Ministry of Environmental Protection and Natural Resources of Ukraine, (2022) Environmental Passport of Sumy Region (as of 01.01.2022).
19. Mordan A.O., Melnyk T.I., (2025) Analysis of species and cultivar diversity of the genus Syringa L. in horticulture. In: Proceedings of the Scientific and Practical Conference of teachers, postgraduate students and students of Sumy NAU, April 14–18, 2025, 136–137.
20. Nowak D.J., Crane D.E., Stevens J.C., (2006) Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening, 4, 115–123.
21. Parmesan C., Yohe G., (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421, 37–42.
22. Peculiarities of cultivation and promising directions for the use of Syringa amurensis L. under the conditions of Podillia, (2021) 13 p.
23. Podieryahin S.O., (2021) Current state and prospects for the use of Meyer lilac under the conditions of SE "Vinnytsia Forestry". Vinnytsia National Agrarian University, 45 p.
24. Potapskyi Yu.V., Bezvikonnyi P.V., Tarasiuk V.A., (n.d.) Decorative evaluation of species and cultivars of the genus Syringa L. Tavriiskyi Scientific Bulletin, 141(2), 38 p.
25. Schwartz M.D., (2013) Phenology: An Integrative Environmental Science. Springer.
26. Skrypak V.R., (2021) Analysis of taxonomic composition and spatial structure of the syringarium of the State Dendrological Park "Oleksandriia" of NAS of Ukraine and ways of its optimization, 6 p.
27. State Register of Plant Varieties Suitable for Dissemination in Ukraine, (2025) Available at: https://sops.gov.ua/ua/derzavnij-reestr.

THE ROLE OF SHELTERBELTS IN ENSURING ENVIRONMENTAL SAFETY IN SOUTHERN UKRAINE

Tetiana Boiko
Associate Professor, Kherson State Agrarian and Economic University
ORCID ID: 0000-0003-3864-2036

Pavlo Boiko
Associate Professor, Kherson State Agrarian and Economic University
ORCID ID: 0000-0003-0658-0846

Forest ecosystems play a pivotal role in the functioning of the biosphere. Due to their high biological productivity, capacity for energy accumulation, and regulation of biochemical processes, they hold global ecological significance [1]. Forests serve as a key element in maintaining the planet's natural equilibrium, ensuring the stability of nutrient cycling and energy flows within natural systems [2]. Through the process of photosynthesis, they sequester significant amount of solar energy, facilitate the synthesis of organic matter and regulate the atmosphere gas composition [3]. At the same time, forest degradation and deforestation reduction lead to the disruption of fundamental ecosystem functions, including energy transformation, biogeochemical cycles, the structural organization of natural complexes and the mechanisms maintaining their dynamic equilibrium. In this regard, expanding the area of forest plantations is considered one of the most effective natural ecological and economic measures for stabilizing the environment and maintain ecological balance in landscapes [4]. Forests perform a multifunctional role within the structure of both natural and anthropogenically transformed territories, acting as a vital regulator of interaction between individual components of geosystems [2]. Conserquently, they serve as an effective tool for managing ecological processes across various types of forest site conditions. Forest plantations are widely utilized in the formation and optimization of the spatial structure of landscapes, as well as in the design of geosystems, natural-territorial and socio-territorial complexes, natural-economic systems, and other functional territorial units.

In the context of modern intensive land resources use and increasing anthropogenic pressure, the implementation of comprehensive measures aimed at enhancing agricultural productivity and preventing land degradation is of particular importance. A key instrument for implementing such measures is the establishment and maintenance of a system of shelterbelt systems designed for various functional purposes [5]. These include field-protective shelterbelts, anti-erosion plantations, riparian buffer strips, water-protection zones and recreational forest areas.

In the scientific literature, such plantations are regarded as integral components of protective forest melioration systems, forming a spatially organized network of conservation elements within the structure of agricultural landscapes [1].

The functioning of these systems ensures a comprehensive impact on natural processes, contributes to the stabilization of the environmental state of territories, enhances the efficiency of land resource use, and creates the prerequisites for the sustainable development of rural areas [6]. In this context, protective forest plantations are regarded as a crucial instrument for the ecological optimization of agrolandscapes and safeguarding their long-term environmental safety.

Under the prevailing conditions in Southern Ukraine, agroforestry and protective afforestation remain among the key national priorities [7].

These lines of activity fulfill a range of critical socio-economic and environmental objectives by leveraging the ecological role of forests in agrolandscapes: protection farmlands from the adverse effects of natural and anthropogenic factors, ensuring the stable functioning of agroecosystems, and creating favorable conditions for the effective development of national economic sectors and the well-being of the population [8]. In the context of Ukraine's intensifying cooperation with the European Union, the ecological role of forest ecosystems is becoming increasingly significant, particularly regarding their integration into programs for designing balanced agricultural landscapes, conserving biodiversity, and implementing sustainable nature management practices on an ecosystem-landscape basis.

Southern Ukraine belongs to the steppe landscapes zone, characterized by increased climate continentality, moisture deficit, significant wind loads and a high level of anthropogenic development [8]. A high degree of lands arability, combined with the natural characteristics of the steppe, creates the prerequisites for the development of erosion processes, soil cover degradation, and a decline in agroecosystems productivity.

Under such conditions, shelterbelts serve as an important element of the ecological infrastructure of agricultural landscapes, capable of mitigating the negative impact of natural factors [9].

Protective forest plantayions create a specific microclimate in adjacent areas, reducing speed, facilitating snow accumulation, and promoting soil moisture conservation [10]. Conserquently, this enhances the resilience of agricultural crops to droughts and temperature fluctuations. Furthermore, shelterbelts perform a vital anti-erosion function by preventing the wind erosion of fertile topsoil. In steppe conditions, they act as a natural barrier that limits the occurrence of dust storms and dry winds.

The problem of preserving and restoring field-protecting shelterbelts takes on particular importance in the context of current climate change [11]. Over recent decades, Southern Ukraine has experienced a rise in average annual air temperatures, a decrease in effective precipitation, and an increasing frequency of arid periods.

Climate transformation lead to the intersification of aridification in steppe regions and the depping of desertification processes [12]. Under such conditions, the role of protective forest plantations as a stabilizing element of agricultural landscapes increases significantly.

Shelterbelts contribute to maintaining the water balance of territories, enhcancing the infiltration of atmospheric precipitation and reduce surface runoff. They also play a vital role in supportimg the biodiversity of agricultural landscapes. Within shelterbelts, habitats are formed for numerous species of plants, insects, birds and small mammals [8]. Thus, protective plantetions act as a unique ecological corridor that facilitate migration and the conservation of various species' populations.

Within the structure of modern agricultural landscapes in Southern Ukraine, shelterbelts function as natural regulators of ecological balance. They contribute to the formation of resilient biogeocenoses and maintain the environmental stability of the region. The presence of an extensive network of protective forest plantations ensures increased productivity of agricultural land and reduces the risk of land degradation [1]. Conserquently, agroforestry measures are regarded one of the key tools for adaptating the agricultural sector to climate change.

At the same time, a significant portion of the field-protective shelterbelts established in the second half of the 20th century are currently in poor condition. Over the past few decades, there has been a gradual reduction in the area of protective plantings, as well as their degradation and fragmentation. The main reasons for this are a lack of proper maintenance, illegal logging, changes in land-use patterns, insufficient funding for forest restoration measures, and an outdated legal framework [13]. As a result, the effectiveness of the field-protective forest strip system is significantly reduced.

Warfare, which broke out across Ukraine in early 2022, has become an additional factor negatively impacting the state of shelterbelts (fig. 1). A significant portion of the southern regions has been directly affected by military operations, leading to the destruction of natural ecosystems and a disturbance of the ecological balance. The shelterbelts system in frontline regions has proven particularly vulnerable, suffering further from hostilities, landmining, fires and the movement of heavy military vehicles [14]. Specific studies note that shelterbelts were frequently used fore military positions, shelters and equipment deployment, leading to direct mechanical and explosive damage to the forest stand, as well as soil contamination with explosive remnants and combustion by-products.

Figure 1. Shelterbelts in the Snigurivka district of the Mykolaiv region damaged by military operations

Fires resulting from shelling led to the loss of significant areas of woody vegetation [15]. In addition to the direct destruction of forest stands, the hostilities caused soil degradation and the contamination of areas with explosive remnants and toxic substances. This significantly hinders the processes of natural recovery of forest ecosystems. In many cases, the restoration of protective plantations will require considerable time and comprehensive environmental measures.

The consequences of military operations are also manifasted in the disruption of ecological connectivity between individual elements of agricultural landscapes. The destruction of shelterbelts leads to a decrease in biodiversity, deterioration of wildlife habitats, and a reduction in the environmental stability of the areas. The loss of these natural barriers exacerbates the negative impact of wind erosion and other degradation processes.

In the post-war period, the restarting and modernizing of the field-protective shelterbelts system take on particular relevant. The formation of an effective network of protective plantations is regarded as a vital direction for ensuring the state's environmental security [14]. The restoration of shelterbelts should become an integral component of comprehensive programs for the reconstruction of the agricultural sector and recovery of natural ecosystems.

Modern approaches to the development of agroforestry involve the application of sustainable natural management principles, ecosystem-based management, and climate change adaptation [3]. An crucial task is to create an optimal agrolandscape structure where shelterbelts serve as key elements of ecological stability. Such plantations must ensure not only the protection of agricultural land but also the maintenance of ecological balance at the regional level.

In the current context of global climate change, research into the processes of atmospheric carbon sequestration by terrestrial ecosystems has taken on particular significance. A vital elements of such ecosystems within the agricultural landscapes is field-protective shelterbelts, which are capable of accumulating substantial volumes of carbon in of woody biomass and the soil cover.

Through photosynthesis, woody plants absorb carbon dioxide from the atmosphere and transform it into organic matter, which accumulates in trunks, branches, foliage, root systems, and litter. Conserquently, forest plantations serve as vital natural carbon reservoirs and play a significant role in regulating the global carbon balance.

Despite their relatively small area compared to lager forest massifs, field-protective shelterbelts possess significant carbon accumulation potential due to their high biomass density and the long-term functioning of their forest stands. They form local pockets of increased biological productivity within agricultural areas, which facilitates the intensification of atmospheric carbon sequestration processes [22]. In addition to carbon sequestration in woody biomass, its accumulation in the soil-resulting from the input of plant residues, litterfall, and the development of root systems – plays an important role [23]. This process contributes to an increase in soil organic matter content and the improvement of its physical and chemical properties.

The study of the potential of carbon sequestration by forest shelterbelts is important for assessing their contribution to mitigating the effects of climate change. In modern conditions of increasing greenhouse gas concentrations in the atmosphere and increasing average annual air temperatures, the search for effective natural mechanisms for reducing carbon load is becoming one of the key areas of environmental policy [24]. Agroforestry plantations can be considered as a component of nature-based solutions [25] aimed at reducing the concentration of carbon dioxide in the atmosphere, mitigating the effects of climate change, and ensuring food and environmental security in the southern region.

Assessment of the carbon sequestration capacity of shelterbelts allows us to determine their role in shaping the regional carbon balance of agro-landscapes. Such studies are also important for substantiating measures for the restoration and optimization of the structure of protective forest stands [22]. The results obtained can be used in the development of strategies for adapting agriculture to climate change, as well as in land management programs and restoration of degraded areas.

In addition to the climate-regulating function, the processes of carbon sequestration in forest are closely related to other ecological effects, in particular, the preservation of soil fertility, the increase in biological diversity and the stabilization of agricultural landscapes. In combination, these processes contribute to the increase in the ecological sustainability of agricultural territories and the formation of more balanced landscape systems. Thus, the study of the sequestration potential of forest shelterbelts is an important direction of modern ecological research, which allows for a comprehensive assessment of their role in ensuring climatic stability and ecological safety of agricultural landscapes.

Research materials and methods

The study of carbon sequestration processes in man-made agroforestry plantations in southern Ukraine was conducted using field measurements, analytical calculations, and a synthesis of scientific sources on agroforestmelioration, forest ecology, and assessment of the carbon balance of terrestrial ecosystems. The methodological basis of the work is the approaches to assessing biomass and organic carbon stocks in tree plantations, which are used in studies of forest ecosystems and agroforestmelioration systems.

The object of the study is artificial forest shelterbelts formed within the agrolandscapes of the steppe zone of southern Ukraine (fig. 2). Such plantations mainly include tree species adapted to the arid conditions of the region, in particular, white locust *Robinia pseudoacacia* L., *Quercus robur* L., *Fraxinus excelsior* L., various species of the *Populus* spp., as well as related species – Acer platanoides, Gleditia triacanthos, Ulmus laevis.

Figure 2. The location of the studied shelterbelts sites

To assess the potential for carbon sequestration, a method was used to determine the phytomass reserves of tree stands with subsequent conversion into the stock of organic carbon [17, 18]. Field studies involve establishing trial plots within forest shelterbelts of different ages and species composition. A tax survey of tree stands is carried out on each trial plot, which includes determining the main biometric indicators of trees: trunk diameter at a height of 1.3 m, total tree height, stand density and species composition. The calculation of tree biomass was carried out using allometric equations that relate trunk diameter to the mass of woody vegetation [19, 20].

The generalized equation for determining the phytomass of an individual tree has the form:

$$B = a \cdot D^b,$$

where B – dry biomass of wood, kg;
D – trunk diameter at a height of 1.3 m, cm;
a, b – empirical coefficients depending on tree species [19-21].

The obtained values – of biomass of individual trees are summed up and converted into indicators per unit area (tons / hectare). After determining the above-ground biomass stock, an assessment of the stock of organic carbon accumulated in woody vegetation is carried out. According to generally accepted approaches in forest ecosystem studies, it is believed that the average carbon content in dry biomass of trees is about 50%. Therefore, the carbon stock is determined by the formula:

$C = B \times 0,5,$

where C – organic carbon stock, t;
B – dry biomass of woody vegetation, t.
IPCC recommends using 0,47–0,5 for woody biomass [19,20].

To assess the climate impact of carbon accumulation, the results are additionally converted into carbon dioxide equivalent. The conversion is carried out using a factor of 3,67, which reflects the ratio of molecular masses of CO_2 and carbon:

$CO_2 = C \cdot 3,67$

where CO_2 – amount of bound carbon dioxide, t [19].

The coefficient is obtained from the ratio of molecular masses:

$44/12=3,67$

In addition to aboveground biomass, the study also takes into account the proportion of belowground biomass represented by tree root systems. To estimate it, the aboveground to belowground biomass ratio is used, which for most hardwoods is 0,20–0,30. This determines the additional organic carbon stock accumulated in the root system.

Soil organic carbon also plays a significant role in the overall carbon balance of agricultural landscapes. Within the shelterbelts, there is a gradual accumulation of organic matter due to leaf fall, dead roots and other plant residues. This contributes to the formation of litter and an increase in the humus content in the upper soil horizons. Within the framework of the study, soil carbon can be assessed by taking soil samples at different depths with subsequent laboratory determination of the organic matter content.

To analyze the efficiency of different tree species in terms of carbon accumulation, a comparative assessment of their productivity and biomass accumulation rates is carried out. Particular attention is paid to species characterized by rapid growth and high adaptability to the arid conditions of the steppe zone. These include *Robinia pseudoacacia* L., various species of the genus *Populus* L., *Fraxinus excelsior* L., *Sophora japonica* L., and others. It is known that fast-growing species provide more intensive biomass accumulation at the initial stages of plantation development, while long-lived species form significant carbon reserves in the long term.

The analysis of the obtained data is carried out using methods of statistical processing and comparative analysis. This allows us to assess the impact of species composition, age of plantations and density of stands on the total potential of carbon sequestration by shelterbelts. The generalization of the research results makes it possible to determine the most effective types of agroforestry plantations for increasing the carbon capacity of agricultural landscapes of southern Ukraine.

The results obtained can be used to justify measures to restore and optimize the structure of shelterbelts, as well as to assess their role in mitigating the effects of climate change and increasing the ecological security of the steppe regions of Ukraine.

Research results

We analysed the CO_2 sequestration potential of the main tree species used in the shelterbelts of the steppe zone of Ukraine. The data are based on a generalization of agroforestry studies, stand productivity, and biomass estimates. Below are indicative figures for stands aged 20–30 years, which is typical for a significant part of the shelterbelts of southern Ukraine.

Table 1. CO_2 sequestration potential of tree species in shelterbelts of the steppe zone of Ukraine

Wood species	Average biomass reserve, t/ha	Carbon stock, t C/ha	Equivalent of bound CO_2, t/ha	Average annual CO_2 sequestration, t/ha/year	Features for the steppe zone
Robinia pseudoacacia L.	80–120	40–60	147–220	5–7	Fast growth, high drought tolerance, nitrogen fixation
Ulmus pumila L.	80-100	40-55	147-202	4-6	High drought resistance, suitable for steppe
Ulmus laevis Pall.	70-100	35-50	128-184	4-5	Forms protective stands well
Elaeagnus angustifolia L.	50-80	25-40	92-147	3-4	Resistant to salinity and drought
Populus spp.	100–150	50–75	184–275	6–9	Very rapid accumulation of biomass
Populus alba L.	100-150	50-75	184-275	6-9	Very fast growth
Populus pyramidalis Roz.	90-140	45-70	165-257	6-8	Very rapid accumulation of biomass
Fraxinus excelsior L.	90–130	45–65	165–240	5–7	High productivity, forms stable stands
Fraxinus lanceolata Borkh.	90-120	45-60	165-220	5-7	Well adapted to steppe conditions
Quercus robur L.	70–110	35–55	128–202	4–6	Slower growth but long-term carbon storage
Acer platanoides L.	60–90	30–45	110–165	3–5	Forms a second tier well
Acer negundo L.	90-120	45-60	165-220	5-7	Well adapted to steppe conditions
Gleditsia triacanthos L.	70–100	35–50	128–184	4–6	Drought-resistant species for steppe conditions
Pinus sylvestris L.	80–120	40–60	147–220	4–6	Effective on dry sandy soils
Morus alba L.	60-90	30-45	110-165	3-5	Drought resistant
Morus nigra L.	60-85	30-42	110-154	3-5	Forms a dense crown
Armeniaca vulgaris Lam.	40-70	20-35	73-128	2-4	Average biomass
Amygdalus communis L.	35-60	17-30	62-110	2-3	Drought-resistant species
Sophora japonica L.	80-110	40-55	147-202	4-6	Tolerates urban and steppe conditions well
Juglans regia L.	90-120	45-60	165-220	4-6	High density wood
Platanus orientalis L.	110-160	55-80	202-294	6-9	Very high biomass
Lonicera tatarica L.	20-40	10-20	37-73	1-2	Shrub, forms undergrowth
Corylus colurna L.	30-50	15-25	55-92	2-3	Forms a shrub layer well
Ligustrium vulgare L.	20-35	10-18	37-66	1-2	Dense protective plantings
Amorpha fruticosa L.	25-45	12-22	44-81	1-2	Average biomass
Tamarix ramosissima Led	30-50	15-25	55-92	2-3	High salt and drought resistance

Analysis of the indicators given in Table 1 shows significant differences between tree and shrub species in terms of biomass accumulation potential and atmospheric carbon dioxide sequestration in the shelterbelts of the steppe zone of Ukraine. As can be seen from the table, the highest biomass indicators and, accordingly, stocks of bound carbon are characterized by fast-growing tree species, in particular, various species of the genus *Populus* and *Platanus orientalis* L. In particular, *Platanus orientalis* forms one of the largest biomass reserves – up to 110–160 t/ha, which ensures the accumulation of up to 55–80 t C/ha and corresponds to approximately 202–294 t/ha of bound CO_2. Similar indicators are also found in *Populus balsamifera* L. and *Populus alba* L., which are characterized by high growth rates and intensive accumulation of organic matter.

High carbon sequestration potential is also demonstrated by *Robinia pseudoacacia*, *Fraxinus excelsior*, *Fraxinus lanceolata* Borkh., *Acer negundo* L. and *Juglans regia* L., which form significant reserves of woody biomass – within 80–130 t/ha. These species are characterized by the accumulation of 165 to 240 t/ha of CO_2 equivalent. Of particular importance among them is *Robinia pseudoacacia*, which combines rapid growth with the ability to fix nitrogen, which contributes to increasing soil fertility and improving the growth conditions of other components of agroforestry plantations.

Among the species with average biomass indicators, it is worth noting *Ulmus pumila* L., *Ulmus laevis* Pall., *Gleditsia triacanthos* L., *Quercus robur* L. and *Sophora japonica* L. Their biomass reserves are usually 70–110 t/ha, which provides the accumulation of approximately 128–202 t/ha of CO_2. An important feature of these species is their high ecological stability and adaptability to the arid conditions of the steppe zone, which makes them promising for the formation of long-lasting and stable protective forest plantations.

Some species, such as *Elaeagnus angustifolia* L., *Acer platanoides* L., *Morus alba* L. and *Morus nigra* L., are characterized by somewhat smaller biomass reserves - within 50–90 t/ha. Accordingly, their carbon sequestration potential is approximately 110–165 t/ha CO_2. However, these species play an important role in the formation of the multi-tiered structure of forest belts, and are also distinguished by increased drought resistance and the ability to withstand adverse soil and climatic conditions of steppe regions.

Fruit trees, in particular *Armeniaca vulgaris* Lam. and *Amygdalus communis* L., have relatively lower biomass accumulation rates – in the range of 35–70 t/ha, which corresponds to 62–128 t/ha of bound CO_2. Despite their lower sequestration potential, these trees can be used as an additional component of agroforestry systems, especially in arid and low-yielding lands.

The lowest carbon accumulation rates are characterized by shrub species such as *Lonicera tatarica* L., *Ligustrium vulgare* L., *Amorpha fruticosa* L., *Tamarix ramosissima* Led and *Corylus colurna* L. Their biomass stock usually does not exceed 20–50 t/ha, which corresponds to 37–92 t/ha of bound CO_2. However, these species have an important functional value in protective forest stands, as they form undergrowth, increase the density of forest belts, contribute to soil consolidation and reduce wind speed.

Thus, the analysis of the carbon accumulation potential shows that the fastest growing tree species, in particular various species of *Populus* and *Robinia pseudoacacia, Platanus orientalis*, have the greatest ability to bind CO_2 among the studied species. These species are capable of accumulating up to 250–290 t of CO_2 per hectare of plantations at the age of 25–30 years. *Fraxinus lanceolata, Ulmus laevis*, *Sophora japonica* and *Juglans regia* are also characterized by quite high indicators. Long-lived species, such as *Quercus robur*, are characterized by lower rates of biomass accumulation, but provide long-term storage of carbon in wood. Shrub species that form the shrub layer have a much lower potential for carbon accumulation, but play an important role in the formation of the multi-tiered structure of shelterbelts and contribute to the additional accumulation of organic matter in the soil. Such plantations are capable of providing annual sequestration of 4–9 t CO_2/ha, making them an important tool for mitigating the effects of climate change in the agro-landscapes of the steppe zone of Ukraine.

Analysis of the table 1 shows that the maximum climate-regulating effect in the field shelterbelts of the steppe zone is achieved through the use of fast-growing tree species with high biomass productivity. At the same time, the formation of effective agroforestry plantations requires a combination of such species with species more resistant to drought conditions, as well as the inclusion of a shrub layer. It is the multi-component structure of plantations that provides not only effective binding of atmospheric carbon, but also increases the ecological stability of agricultural landscapes, helps protect soils from erosion and creates favorable conditions for the functioning of biodiversity.

The role of shelterbelts in preventing soil erosion and dust storms

One of the important ecological functions of shelterbelts is to restrain wind erosion processes and prevent the formation of dust storms. In the steppe regions of Ukraine, where natural landscapes are characterized by significant openness of the territory and high wind speed, forest belts play the role of natural barriers that reduce the intensity of air flows and stabilize the surface layer of the soil. It is known that the system of protective forest plantations is capable of reducing wind speed in adjacent territories by 30–70%, and the zone of their protective influence can extend to a distance that is 20–30 times the height of the tree stand.

The problem of dust storms in the steppe zone of Ukraine has a long history and is directly related to the state of vegetation cover and the structure of agricultural landscapes. The most extensive manifestations of wind erosion were observed in the first half of the twentieth century, when significant areas of steppe territories were intensively plowed, and natural protective elements of the landscape practically disappeared. In the 1920s and 1930s, powerful dust storms were regularly recorded in the southern and eastern regions of Ukraine, accompanied by the movement of significant masses of soil material over long distances. According to researchers, during periods of strong dry winds, losses of the fertile soil layer could reach several tens of tons per hectare, which led to a sharp decrease in the productivity of agricultural lands and the degradation of land resources [1, 2].

In response to large-scale manifestations of deflation and soil degradation in the second half of the 20th century, a comprehensive program of agroforestry reclamation measures was developed. An important stage in this process was the adoption in 1948 of the state program for the creation of a system of field shelterbelts aimed at stabilizing the agrolandscapes of the steppe and forest-steppe regions. The implementation of this program provided for the formation of an extensive network of shelterbelts that were to perform anti-erosion, climate-regulating and soil-protective functions. Over the following decades, tens of thousands of kilometers of field shelterbelts were created in the steppe zone of Ukraine, which significantly changed the structure of agrolandscapes [26, 27].

Scientific studies of the second half of the 20th century showed that the creation of a system of shelterbelts led to a significant reduction in the intensity of wind erosion. Protective plantings reduced wind speed, contributed to the accumulation of snow and increased soil moisture, which largely prevented the formation of dust storms. In many areas of the steppe zone, their frequency and intensity significantly decreased, and agro-landscapes became more ecologically stable [3, 28].

However, at the end of the 20th and beginning of the 21st centuries, the situation began to gradually change. A significant part of the shelterbelts created in previous decades was in unsatisfactory condition due to aging stands, lack of proper care, illegal logging, and changes in land use. As a result, the efficiency of the agroforestry and reclamation network has significantly decreased. At the same time, the manifestations of climate change have intensified, characterized by an increase in air temperature, a decrease in the amount of effective precipitation, and an increase in the frequency of dry periods.

An additional factor aggravating the problem was the consequences of hostilities in Ukraine, which caused significant damage to natural ecosystems, including forest protection strips [15]. Fires, explosions and the movement of heavy machinery led to the destruction of part of the protective plantings and the degradation of the soil cover [14]. In combination with the increased aridity of the climate, this creates the prerequisites for the reactivation of wind erosion processes and the emergence of dust storms in the steppe regions, in particular in the territory of the Left Bank of Ukraine.

Thus, historical analysis shows that the formation and maintenance of a system of shelterbelts plays a key role in containing dust storms and ensuring the ecological stability of agrolandscapes. Restoration and modernization of agroforestry plantations in modern conditions is considered an important direction for increasing the ecological security of the steppe regions of Ukraine.

However, over the past decades, a significant part of the shelterbelts of southern Ukraine has been in a degraded state. The aging of the stands, the lack of proper care and the partial destruction of woody vegetation have led to a decrease in the efficiency of the functioning of the agroforestry system. In combination with the increasing aridity of the climate, this creates the prerequisites for the intensification of soil deflation processes.

As mentioned above, the situation has been significantly complicated by hostilities, which have damaged or destroyed a significant part of the forest ecosystems of the Left-Bank Ukraine. The destruction of shelterbelts, fires and soil degradation contribute to the formation of conditions for the occurrence of dust storms. Such phenomena pose a serious threat to agricultural landscapes, as they are accompanied by the loss of the fertile soil layer, deterioration of atmospheric air quality and a decrease in the productivity of agricultural lands.

In this context, the restoration and modernization of the system of shelterbelts is considered one of the key areas for increasing the ecological sustainability of agricultural landscapes in southern Ukraine and preventing the development of dangerous natural and anthropogenic processes.

Analysis of the indicators given in Table 1 shows that the use of the specified tree and shrub species in the composition of shelterbelts can significantly reduce the manifestations of wind erosion of soils and prevent the formation of dust storms in the steppe zone of Ukraine. This is due primarily to the significant biomass of tree stands, developed crown and the ability to form dense or openwork-blown structures of shelterbelts, which effectively reduce the wind speed above the soil surface.

The most effective in forming the anti-erosion framework of agrolandscapes are fast-growing species with a large biomass reserve, in particular various species of Populus, Robinia pseudoacacia, species of Fraxinus and Platanus. According to the table, these species form the largest reserve of organic mass - up to 100–160 t/ha, which ensures high crown density and significant height of stands. Due to this, they create a powerful aerodynamic barrier, which is able to reduce the speed of wind flows at a distance that is 10–15 times higher than the height of the forest belt. As a result, the ability of air flows to lift and carry small soil particles, which are the main source of dust storms, is sharply reduced.

An important role in protecting soils from deflation is also played by medium-yielding species, in particular *Ulmus pumila*, *Ulmus laevis*, *Gleditsia triacanthos*, *Quercus robur* and *Sophora japonica*. These species are characterized by high ecological stability and the ability to form long-lasting stands with a branched root system. Tree roots fix the soil cover, reducing its loosening and increasing the soil structure. This significantly reduces the risk of wind erosion, especially in open steppe areas.

Drought-resistant species such as *Amygdalus angustifolia*, *Tamarix ramosissima*, *Morus alba* and *Morus nigra* are equally important in the structure of field protection stands. They are well adapted to the extreme conditions of the steppe, in particular to moisture deficiency, high temperatures and saline soils. The presence of such species in the composition of forest belts ensures the stability of stands even in adverse climatic periods, which is an important factor in the long-term functioning of anti-erosion systems.

Shrub species, in particular *Lonicera tatarica*, *Ligustrium vulgare*, *Amorpha fruticosa* and *Corylus colurna*, form the lower tier of shelterbelts and play an important role in reducing the speed of the surface layer of air. It is in the surface layer that the main part of deflation processes takes place, since small soil particles are lifted by the wind to a height of several tens of centimetres. The shrub layer reduces the turbulence of air flows and contributes to the settling of dust particles, which significantly reduces the intensity of dust storms.

Thus, the effectiveness of forest shelterbelts in combating wind erosion is determined not only by the growth rate of individual species, but also by the correct selection of their combination in the composition of the stands. The most effective are multi-tiered forest belts, which combine tall fast-growing trees, medium-sized resistant species and a dense shrub layer. Such a structure provides uniform braking of air flows at different heights, contributes to soil consolidation and reduces the risk of dust storms. As a result, shelterbelts are an important element of ecological stabilization of agrolandscapes of the steppe zone and an effective natural mechanism for restraining wind erosion processes.

Conclusions

In the current conditions of Ukraine's development, agroforestry reclamation and the creation of protective forest plantations remain one of the important strategic directions of the state environmental policy and rational nature management. Their importance is due to the need to ensure the ecological stability of agricultural landscapes, preserve soil fertility and increase the resistance of agricultural production to adverse natural and anthropogenic influences. The development of agroforestry reclamation systems is particularly relevant in the context of modern climate change, which is accompanied by an increase in the frequency of dry periods, an increase in air temperature and an increase in degradation processes in the soil cover. In such conditions, protective forest plantations play the role of an important stabilizing element of agricultural landscapes, contributing to the adaptation of the agricultural sector to new climatic challenges.

In the context of the intensification of integration processes and the deepening of cooperation between Ukraine and the European Union, the role of forest ecosystems in the implementation of modern approaches to natural resource management is significantly increasing. European environmental policy pays significant attention to the formation of balanced landscapes, the preservation of biological diversity and the implementation of the principles of sustainable development. In this regard, forest plantations are considered an important tool for implementing programs to design ecologically balanced agricultural landscapes, form an ecological network and maintain natural balance in anthropogenically transformed territories.

The introduction of an ecosystem-landscape approach to natural resource management involves the integration of forest elements into the structure of agro-landscapes, which allows increasing their ecological sustainability and ensuring more rational use of land resources. In this context, agroforestry is one of the key mechanisms for implementing the principles of sustainable nature management and ensuring long-term ecological security of territories.

REFERENCES

1. Furdychko O.I. & Stadnyk A.P. (2008). Forest reclamation as a major factor in the stabilization of steppe ecosystems. Ecology and Noospherology, 19(3-4), 13-24.
2. Hladun H.B., Hladun Yu. H. & Yukhnovskii V. Yu. (2013). Optimization of plantations of forest-melioration complex on adaptive-landscape basis. Scientifi c Bulletin of National University of Life and Environmental Sciences of Ukraine. Series: Forestry and Decorative Gardenin, 187(2), 104-111.
3. Kucheryavyi V. P. (2001). Forest Ecology. Lviv: Svit. 424 p.
4. Furdychko O. I., Gladun G. B., Lavrov V. V. (2006). Forest in steppe: foundations of sustainable development. Kyiv, 496 p.
5. Mykolaiko V. P., Kyryliuk V. P., Kozinska I. P. (2020). Forest shelterbelts as agricultural land. Balanced Use of Natural Resources. No. 2. 84–93.
6. Boiko T.O., Boiko P.M., Pluhatar Y.V. (2019). Ecological Forestry. A textbook. Second edition, revised and expanded. Kherson: Oldi Plus. 268 p.
7. Strelchyuk L. M., Boiko T. O. (2015). The current state of the shelter belts of Kherson Region (Ukraine). Chornomorsk. bot. z., 11 (3): 373–378. https://doi.org/10.14255/2308-%209628/15.113/10
8. Boiko T., Boiko P., Breus D. Optimization of shelterbelts in the steppe zone of Ukraine in the context of sustainable development. 18-th International multidisciplinary scientific geoconference SGEM 2018, 2018 Vol. 18, Issue: 3.2. doi:10.5593/sgem2018/3.2
9. Vysotska N. Y., Zubov O., Zubova L. & Fomin V. (2019). State of the protective forest belts of various purposes in the Oleshky district of Kherson Region. Forestry and Forest Melioration. 135. 85-97. https://doi.org/10.33220/1026-3365.135.2019.85
10. Boiko T. O., Dementieva O., Boiko P. (2019). The phytomeliorative functions of green spaces as a factor in the sustainable development of the Kherson region. Proceedings of the XII International Scientific and Practical Online Conference ‘Problems and Prospects for the Development of Modern Science in European and Asian Countries’. Collection of Scientific Papers. Pereyaslav-Khmelnytskyi, 17–18.
11. Chepurda G. M. (2015). The environmental consequences of establishing a system of field-protective forest belts in Ukraine. Historical Archive. Scientific Studies. No. 14. pp. 94–99.
12. Tkachuk O. P. & Viter N. G. (2022). Biological aspects of the functioning of field-protective forest belts under conditions of climate change. Balanced Nature Management. No. 3. 62–69.
13. Sharyi G., Odaryuk T., & Shara, S. (2024). EVOLUTION OF FORESTRY LAND USE DEVELOPMENT AND RESTORATION OF SHELTERBELTS IN COMMUNITIES. *Bulletin of Lviv State University of Life Safety*, *30*, 145-153. https://doi.org/https://doi.org/10.32447/20784643.30.2024.14
14. Boiko T.O., Tsukalenko V.V. (2024). Assessment of the impact of hostilities on the condition of forest ecosystems in southern Ukraine. Current trends in the development of agricultural science: proceedings of the International Scientific and Practical Conference (Kherson State Agrarian and Economic University, 17–18 September 2024). Kherson: Kherson State Agrarian and Economic University.
15. Konishchuk V., Khomiak I., Shumyhai I., Onyshchuk I. (2025). Vegetation dynamics of field protective forest strips affected by military actions of various intensities. Agroecological Journal. No. 1. 78–86. https://doi.org/10.33730/2077-4893.2.2025.333813
16. Hetman P. A. (2023). Protective shelterbelts – integral component of the regional eco-network (Kirovohrad region). Chornomorski Botanical Journal, *19*(4), 365–378. https://doi.org/10.32999/ksu1990-553X/2023-19-4-3
17. IPCC Guidelines for National Greenhouse Gas Inventories. (2006). Volume 4: Agriculture, Forestry and Other Land Use. Hayama, Japan: Institute for Global Environmental Strategies. https://www.ipcc-nggip.iges.or.jp/public/2006gl/ (date accessed 07.03.2026).
18. Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. (2019). Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/ (date accessed 07.03.2026).
19. Brown S. (1997). Estimating Biomass and Biomass Change of Tropical Forests: A Primer. Rome: FAO. 55 p.
20. Chave J., Andalo C., Brown S. et al. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia. Vol. 145. 87–99.
21. Zianis D., Muukkonen P., Mäkipää R., Mencuccini M. (2005). Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs. No. 4. 63 p.

22. Nair P. K. R., Nair V. D., Kumar B. M., Haile S. G. (2009). Carbon sequestration in agroforestry systems. Advances in Agronomy. Vol. 108. 237–307.
23. Nowak D. J., Crane D. E. (2002). Carbon storage and sequestration by urban trees in the USA. Environmental Pollution. Vol. 116. 381–389.
24. Montagnini F., Nair P. K. R. (2004). Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforestry Systems. Vol. 61. 281–295.
25. Lal R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science. Vol. 304. P. 1623–1627.
26. Bodrov, V. A. Shelterbelts. Kyiv: Urozhay, 1970. 216 p.
27. Pylypenko, O. I. Agroforestry. Kyiv: Urozhay, 1978. 280 p.
28. Bulygin, S. Yu., Nearing, M. A., & Achasov, A. B. (2003). Assessment and Forecasting of Land Quality. Kharkiv: Kharkiv National Agricultural University. 312 p.

MACLURA POMIFERA: GROWING OF PLANTING MATERIAL AND ITS USE IN THE NATIONAL ECONOMY

Tokman Volodymyr
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0002-1237-4611

The ornamental and medicinal properties of *Maclura pomifera* (habitus, beautiful foliage, fruits) make it one of the promising taxa for use in alternative medicine and landscape design [2, 5-7, 9]. It is used in various compositions in the form of single-stem plantings, hedges, and protective strips.

In European countries, the fruits of this cultivar are used to make medicines, and in folk medicine, a tincture is used to treat joint pain and rheumatism. The wood is used to make furniture, the leaves are used as food for silkworms, and the bark and roots are used to make a valuable dye [8]. As of 2020, there was virtually no demand for planting material for this valuable medicinal and ornamental plant.

Relevance. The insufficient amount of planting material of *M. pomifera (Rafin.) Scheid* in the nurseries of our country is due to the low awareness of specialists regarding effective methods of propagation of this plant and the lack of information about adaptive capabilities in the areas of its introduction.

The purpose of the work is to study agrotechnical measures for growing planting material *M. pomifera* in the conditions of the northeastern Forest-Steppe.

To achieve this goal, the following main tasks have been identified:

– to analyze the experience of growing planting material *M. pomifera* based on literary sources;
– to assess the influence of the depth of seed sowing on its soil germination;
- to consider the influence of the type of substrate on the growth and development of seedlings;
- to study the influence of hormonal compounds on laboratory seed germination;
- to consider possible options for using *M. pomifera* in the national economy.

The object of research is *M. pomifera.*

The subject of research is the technology of growing planting material of *M. pomifera.*

The Moraceae family includes 55-60 genera and 1400-1650 taxa of deciduous or evergreen trees, lianas, shrubs, annual and perennial plant organisms [17-20]. Many of its species are cultivated by humans. In Ukraine, plants of the genus Morus are grown, and in Crimea - taxa of the genera *Maclura* and *Ficus* [20]. The family is characterized by polymorphism, specialization of many organs, and the absence of clear differences from other families, which, given the large number of species, makes their classification difficult. The family includes six subfamilies: *Moreae, Ficeae, Artosagreae*, and others [13, 17-18]. The subfamily *Moreae* differs from other subfamilies in having unisexual flowers collected in panicles, catkins, and spike-like inflorescences. The subfamily includes ten genera and about 70 species of monoecious and dioecious plants with a very wide range. Representatives of the genus *Morus L.* are confined to the temperate zone [13].

The genus *Maclura* belongs to the family *Moraceae* and includes 11 taxa [17, 21].

These are trees, shrubs, and climbing plants with strongly developed axillary spines. They are widespread in the subtropical and tropical zones of Africa, America, and Asia (Fig. 1).

Figure 1. Distribution area of Maclura

They are used to create thorny hedges, in ornamental plantings (solitary and group) [11, 20], and the wood is used in carpentry and construction. In addition, yellow paint is made from the root system of *Maclura tinctoria*. At the same time, only *M. pomifera* is widely used as an ornamental and deciduous crop, and the fruit is used in alternative medicine.

Figure 2. Maclura pomifera (Raf.) Schneid

M. pomifera is a single-stemmed prickly tree up to 20 m high and up to 0.50 m in diameter (Fig. 2). The crown is ovoid, in old trees it is spreading and dense. Strongly developed root system penetrates deeply into the soil. In the first 8-10 years, it has extremely intensive growth, which slows down with age. Plants are resistant to summer droughts, as well as to low temperatures in winter down to -32,2^{0}C. The growing season is 180-195 days, and the dormant season is 170-180 days. All parts of the plant contain a milky sap [30-32].

The plant is named after the famous American cartographer, geologist and philanthropist William Maclure (1753 - 1830) [15].

Figure 3. Shoot M. pomifera

Young shoots are green, pubescent, and woody ones are bare, brown, shiny. The bark of the plants is dark (Fig. 3), brown with furrows and cracks. The branches are knee-curved, the shoots are prickly, typical for the mentioned taxon. Spines up to 24 mm long, are slightly curved, formed in the leaf axils. Buds are 1.7-2.3 mm long, scales are numerous, rounded (Fig. 3) [31].

Figure 4. Leaves of M. pomifera

The leaf surface (Fig. 4) is ovate-elongated, dark green, shiny, 8-14 cm long, and up to 7 cm wide. The leaves are entire. The arrangement is alternate. Autumn color is yellow [34].

Figure 5. Inflorescence of M. pomifera

Flowers are dioecious, small, axillary, spherical, green in color (Fig. 5). The flower has 4 stamens and 4 sepals. Stamen flowers are collected in catkins 30-40 mm long, and female flowers are collected in spherical heads (up to 30 mm in diameter) (Fig. 5). Flowering occurs in May-June. Flowering of plants occurs within 15-20 days [13]. At the same time, annual flowering and fruiting of trees has been recorded in the Crimean conditions [18].

Figure 6. Progeny of M. pomifera

The plant forms large spherical inedible fruitlets (Fig. 6) (400-600 g) with a diameter of 12-15 cm, golden-greenish in color with milky juice, covered with a sticky liquid [10, 34]. When ripe, the color changes to orange. The fruits ripen in the second half of September. Inside the fruits there is a milky juice, which is released when cut. The smell when cut resembles a fresh cucumber. The trees are especially spectacular during the fruiting period. The yield from one tree is about 60 kg of fruit.

Figure 7. Seeds

They contain up to 400 seeds (Fig. 7), stored for up to 7 months. The mass of 1000 seeds is 27.9 g, and their average number in the fruit is 120 - 150 pieces. [3-4]. It is not recommended to store seeds for more than 3 years due to a significant loss of their seeding suitability (from 90 to 10%). The optimal time for collecting seeds of *M. pomifera* in the Right Bank Forest-Steppe is the third decade of September - the first decade of October, and the optimal period for sowing it in open soil is the first decade of May.

Freshly collected seeds are used for propagation. It was found that the sowing quality of *M. pomifera* seed material and its size depend on the amount of moisture during the growing season.

Figure 8. M. pomifera sawn

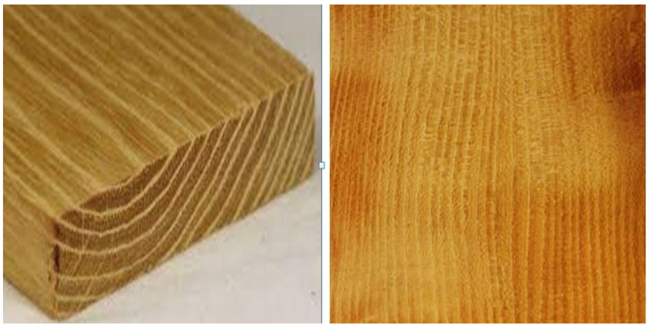


Figure 9. M. pomifera lumber

Maclura wood (Fig. 8-9) is dense, strong, and at the same time flexible and attractive in appearance [14, 19]. It has a yellow-golden color (as if filled with sunlight), is used for the manufacture of furniture and household items (Fig. 10).

Figure 10. Household items

It is stronger than *Quercus* in terms of mechanical and physical properties, and is therefore used for engraving work. It is easily polished, but difficult to drill [2].

It is quite difficult to perform carpentry work with this material. It is poorly sawn and planed. Native Americans used *Maclura* wood to make weapons (clubs and bows). Hunting and sports bows made from its wood are superior in quality to those made from *Taxus* [36].

The conducted analysis of the literature on the frost and winter hardiness of *M. pomifera* in various soil and climatic conditions creates the opportunity to draw conclusions about the resistance of the named taxon to adverse wintering factors: it withstands a decrease in temperature to -30°C.

In addition, it is classified as a drought-resistant plant species, in which significant damage to leaves and shoots is not observed in the summer heat.

The cultivar is fast-growing, heat- and light-loving, moderately demanding on the soil environment and humidity. It has been studied that *M. pomifera* tolerates both a deficiency of moisture in the soil and its excess. At the same time, in relation to the humidity of the soil environment, it is a mesoxerophyte, and in relation to the reaction of the soil environment, it belongs to indifferent plant organisms. The best soil for the growth and development of the mentioned taxon is podzolized black soil.

The cultivar grows naturally in the states of Texas, Virginia, and Georgia in the USA. *M. pomifera* is cultivated in the southern and western regions of Ukraine.

It is used in green farming and as a medicinal plant. It has excellent, strong wood that is resistant to rot. The plant is also used as a rootstock for *Cudrania tricuspidata* ("strawberry tree"), whose fruits are tasty and quite common [15].

City, methodology and research design. Research on seed propagation of *M. pomifera* was carried out on the basis of the training laboratory of the Department of Horticulture and Forestry. It should be noted that the seed material was collected from fruit-bearing plantations of the Poltava Agrarian and Economic College (Fig. 11-12).

In Ukraine, the laboratory method for determining the quality of seed material is germination. The mentioned method provides the opportunity to determine the number of germinated seeds and the qualitative state of seedlings. Qualitative indicators of seed material were determined in accordance with State Standard (GOST) 13056.6-97 [12, 13].

Figure 11. Fruits of M. pomifera

Figure 12. Seeds of M. pomifera

Before germination, it was soaked for 20 hours at a temperature of 18-20°C. After that, the seeds were washed and spread out in Petri dishes.

The study of the influence of hormonal compounds on the soil germination of *M. pomifera* seed material was carried out in the conditions of a closed ground construction.

Seeds were sown in the second decade of April (15.04). To form the soil mixture, forest soil and river sand were mixed.

The research work was carried out according to the following scheme:

Factor A – biologically active substances: 1) epin; 2) baikal; 3) control (water); 4) charkor. Factor B – the influence of seed sowing depth on germination: 1) control (10-20 mm); 2) 20-30 mm; 3) 30-40 mm; 4) 40-50 mm; 5) 50-60 mm; 6) 60-70 mm. Factor C – the influence of the substrate on the growth of planting material: 1) soil + sand (2:1); 2) soil + humus (2:1); 3) soil + peat (2:1); 4) control (field soil).

After removing the seeds from the fruits, they were washed in water. The seed material was stored at room temperature in paper bags. The experiment was set up in 3 replicates, where 100 pcs. of seeds were sown.

During the growing season, agrotechnical measures were carried out for the seedlings: removal of weeds and watering.

The research work was carried out according to the methodology [12, 27]. Statistical data processing was carried out [24].

Research results. According to Sokolov S. Ya. [4, 33], *M. pomifera* can be propagated by seeds and cuttings (green and lignified) [23, 25-26].

Experience with the introduction of new taxa shows that generative propagation improves the resistance of the new generation to adverse environmental factors. This is especially important for thermophilic cultivars, to which the mentioned taxon belongs [30, 32].

Seed propagation (Fig. 13), and especially its comparative analysis, is an important indicator of the success of the introduction.

Figure 13. M. pomifera seedlings

Table 1. Qualitative indicators of *M. pomifera* seedlings

	Variant	Height, cm	± to control	Thickness, mm	± to control
1.	Soil + sand (2:1)	19,5	-0,2	2,2	- 0,1
2.	Soil + humus (2:1)	22,3	+ 2,6	2,4	+ 0,2
3.	Soil + peat (2:1)	21,0	+ 0,3	2,6	+ 0,3
4.	Control (field soil)	19,7	-	2,3	-
HIP $_{05}$		2,14			

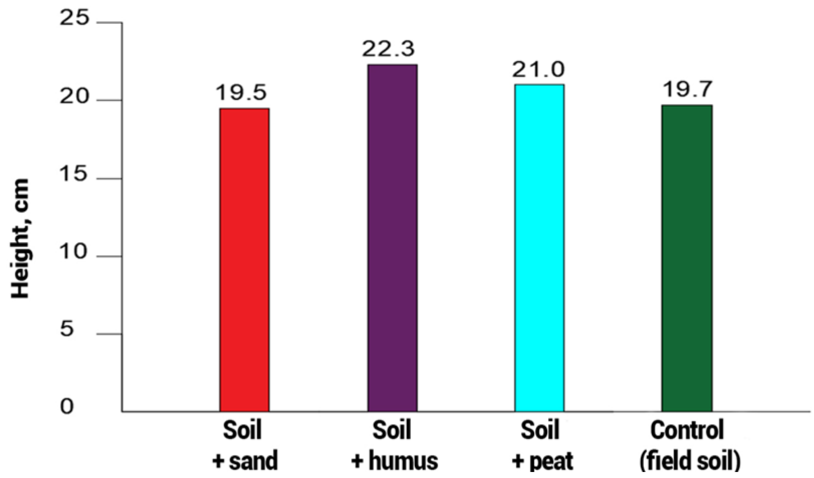


Figure 14. Effect of substrate type on the height of annual seedlings

Observations of the growth and development of *M. pomifera* seedlings on different soil mixtures (Table 1, Fig. 14) made it possible to find out that they grew best in the second variant (soil + humus).

The height of the seedlings in the mentioned variant was 22.3 cm, which is 2.6 cm more than in the control.

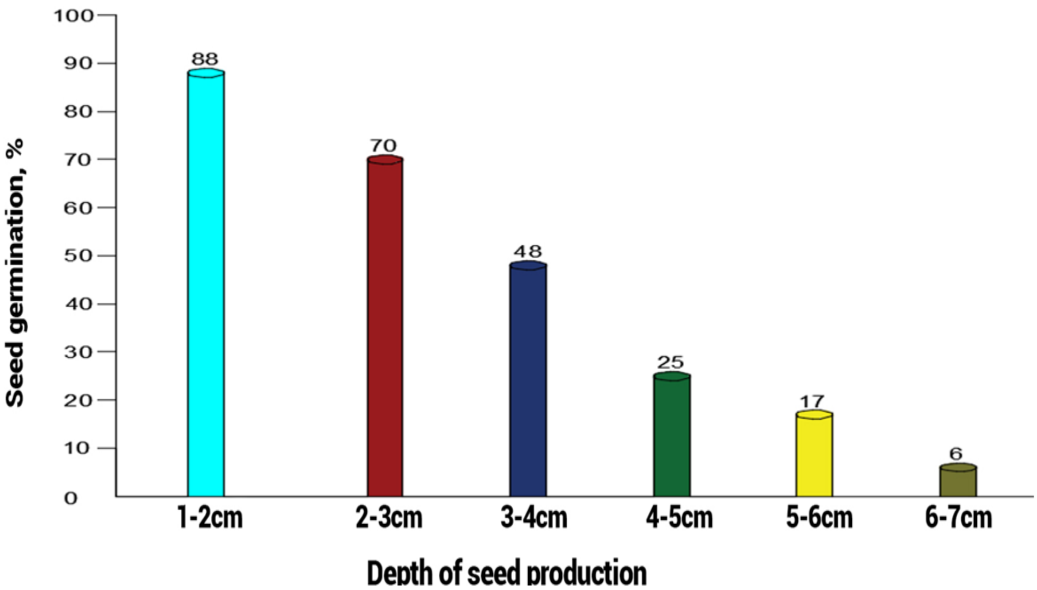


Figure 15. Germination of M. pomifera seeds

The thickness of the root collar in the experimental variants was within 2.2-2.6 mm. In addition, in the process of carrying out experimental work, the influence of the depth of seeding on soil germination was considered (Fig. 15).

According to the results obtained, in closed soil conditions, the maximum germination of the seed material (88%) was in the variant of sowing it to a depth of 10-20 mm. At the same time, when sowing seeds to a depth of 30-40 and 40-50 mm, a significantly worse result was obtained - germination was 48 and 25%, respectively. Under the conditions of sowing seed material to a depth of 60-70 mm, the minimum result was 6%. 25 days after the appearance of the first shoots, true leaves appeared.

Thus, the optimal depth of seed sowing, which ensures maximum field germination, in the conditions of the cultivation structure (10-20 mm), was found by research.

The study of the dynamics of growth processes in seedlings during the growing season was carried out in closed soil conditions (Fig. 16).

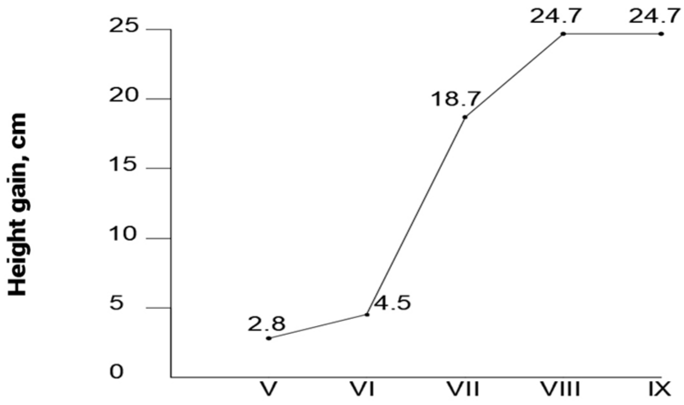


Figure 16. Growth dynamics of M. pomifera seedlings

Analyzing the results obtained, we emphasize that the maximum intensity of seedling growth was observed during June - August (4.5 to 24.7 cm). At the same time, the average height of seedlings during the growing season was 24.7 cm.

To restore the biochemical activity of seed tissues and ensure the growth of the embryo, it is necessary to create conditions for its germination. This is achieved by soaking, scarification, snowing, etc. [1, 20, 29]. At the same time, the above-mentioned measures for preparing seed material for sowing only ensure overcoming the state of forced dormancy in seeds, but do not affect the survival and growth of seedlings. It is known that pre-sowing seed preparation reduces the time for growing planting material.

Today, in Ukraine and abroad, growth regulators are widely used in the production of planting material for both forestry and horticultural purposes [16]. At the same time, attention is paid to compounds that are made on the basis of natural raw materials [27-28].

Table 2. Germination duration and germination of *M. pomifera* seeds

№	Option	First sprouts appearance	The emergence of mass sprouts	Germination period, days	Seed germination, %
1.	Control (water)	7.05	16.05	40	88,0
2.	Epin	1.05-	6.05-	33	92,0
3.	Baikal	2.05	7.05	31	93,0
4.	Charkor	1.05	6.05	30	93,0

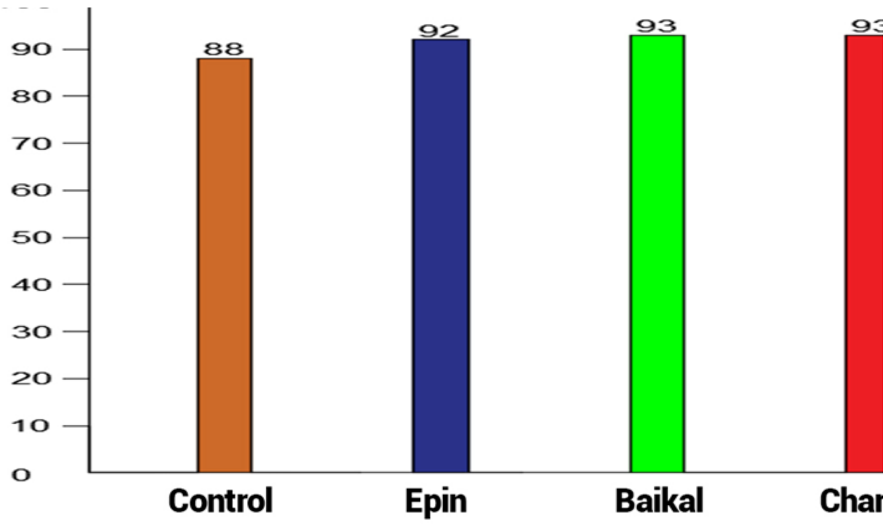


Figure 17. Effect of growth regulators on seed germination of M. pomifera

To determine the influence of physiologically active compounds on the germination processes of *M. pomifera* seeds, we performed experimental studies to determine their germination (Table 2, Fig. 17).

The first shoots of *M. pomifera* appeared in the experimental variants on the 15-17th day, and in the control - on the 22nd day after the germination. The maximum germination intensity in the control variant was noted on the 31st day, and in the experimental variants - on the 21-22nd day. The seed germination rate in the control variant was 88%, which is 4-5% less than in the search variants.

Figure 18. M. pomifera

M. pomifera (Fig. 18) is a wonderful ornamental tree with inedible fruits. It is planted in parks and gardens. Due to its decorative, beautiful wide crown, shiny and long leaves and original fruits, it is used in landscape design. The thorns make it possible to use it to create protective strips.

The *M. pomifera* tree can grow up to 18 m in height, which makes it an excellent material for creating shade or hedges. It grows intensively, which makes it possible to achieve the appropriate decorative effect in the garden plot quickly.

Figure 19. Single plantings of Maclura

Figure 20. Group plantings of Maclura pomifera

In ornamental gardening of park plants, it is practiced to plant *M. pomifera* in the form of single (Fig. 19) and group plantings (Fig. 20), elegant lawns that create partial shade for shade-tolerant shrubs and low-growing trees.

Figure 21. Field protection plantings of M. pomifera

M. pomifera is widely used in erosion control plantings, buffer strips, and reclamation plantings (Fig. 21). In private households, it is used to create elegant living fences that protect homestead plots from uninvited guests, including hares.

The mentioned cultivar grows well in the sun, tolerates light shade. It prefers fertile and well-aerated soil, but it is unpretentious and can grow on any soil. Even saline soils are suitable for it. Due to its well-developed root system, the tree is able to absorb nutrients and water from deep soil horizons, which provides it with resistance to arid conditions. The plant is resistant to frost (-30°C) and winds. It tolerates anthro pyogenic conditions well. To intensify growth processes, it is advisable to prune at a young age.

Planting of planting material with an open root system is recommended in the spring, when frosts have passed. It is advisable to prepare the planting hole in advance, forming a drainage system. In the first growing season after planting the seedling, it is necessary to water it regularly, and mulch the trunk circle. Plant feeding is not required. Sanitary pruning of the crown is performed annually, and shaping once every three years. The above-ground part of young plants is protected with agrofibre in the cold season.

M. pomifera is suitable for landscaping urban areas and forming ornamental plantings. Its fruits are not edible, but are a component for the manufacture of medicines that are popular in alternative medicine.

To date, official medicine has studied *M. pomifera* little, but it has recognized it as a source of valuable beneficial compounds.

The fruit pulp (Fig. 22) of *M. pomifera* contains osagin and pomiferin, which are present in the fruit in a ratio of about 1: 2 by weight, and, at the same time, constitute 5-7% of the weight of dry fruit. Fresh fruits include pectin (45%), sugar (up to 5%), fat (6%), resin (16%). The water content in the fruit pulp is approximately 70% [4].

Figure 22. Fruits of M. pomifera

The fruits of *M. pomifera* contain:
- Flavonoids - highly active anticarcinogens and antioxidants.
- Isoflavones - intensify and improve metabolic processes.
- Sterols - improve the absorption of vitamins of various groups (B, E. C, A and D).
- Pectin. Necessary for collagen synthesis. Minimizes cholesterol content. Provides removal of toxins and salts from the body.
- Citric acid is useful for joints, and also creates prerequisites for the removal of uric acid from the body.
- Bioflavonoids have a regenerating and analgesic effect. Improves the elasticity of blood vessel walls.
- Saponins are necessary for the absorption of beneficial compounds. They ensure the restoration of the body's salt, mineral and water balance.
- Bile acids. Optimize fat metabolism.
- Fatty acids have a positive effect on the immune system.

The seed oil of *M. pomifera* contains linoleic, oleic, palmitic and stearic acids. The content of the fruits and extracts indicates the presence of calcium, phosphorus, potassium, silicon, magnesium and sodium.

Figure 23. Sciurus vulgaris feasts on the fruits of M. pomifera

The fruits of the mentioned species are not poisonous, but they are not edible, because they have a dry, bitter pulp. The seeds of the fruits are edible, if they are roasted, they taste a little like sunflower seeds. *S. vulgaris* willingly eat the seeds of *M. pomifera* (Fig. 23). Information about the toxicity of the fruit is erroneous, possibly due to imperfect translation. It is advisable to remember that the concentrated juice is poisonous and can cause burns if it comes into contact with the skin and mucous membranes [13].

M. pomifera, as a medicinal plant, has been long and widely used in folk medicine in many countries of the world. In particular, in Bolivia, the bark and leaves are used for internal bleeding, the fruit juice is used to treat toothache, and lotions are made from a decoction of the root system against eye inflammation.

Figure 24. Medicines from the fruits of M. pomifera

In folk medicine, medicines are made from the fruits of *M. pomifera* (Fig. 24): ointments, tinctures, compresses and rubbing products, decoctions [13].

Figure 25. Pharmaceutical medicines based on M. pomifera

Most often, medicines from *Maclura* fruits are used in the form of a rub, ointment or tincture (Fig. 25). In addition, oil extraction of the fruits is carried out in the manufacture of medicines.

Maclura tincture is considered effective. It is used as a medicine for the following diseases: varicose veins; fibroids; hypertension; bruises, joint pain; colds; polyarthritis and gout; eczema; partial paralysis after a stroke; mastopathy; prostate adenoma; oncology.

In addition, tincture of *M. pomifera* is used for rubbing for the following diseases: rheumatism, radiculitis, osteochondrosis (rubbed on diseased areas of the body) [36]. The course of treatment is up to 7 days with a break of 30 days.

For sinusitis, compresses are made from the tincture. Soaked tampons are kept in the nose for 15 minutes. The course lasts 5 days (done twice a day).

Studies have shown that the alcoholic extract of *Maclura* fruits negatively affects the activity of the enzymes collagenase, hyaluronidase and elastase, which directly affect the aging process of the human body. In this way, it was proven that the compounds of the mentioned plant should be used in the production of anti-aging cosmetic products.

There is information about the sufficient effectiveness of the extract from the seeds of *M. pomifera* against acne, age spots and other skin diseases.

Despite the healing properties of *Maclura* fruits, it is advisable not to forget about its toxicity [35]. In the process of manufacturing medicines, it is necessary to strictly observe the proportions and use them in appropriate doses. In addition, it is advisable to consult a doctor before using the products.

The literature contains information about the effectiveness of the plant in the treatment of breast cancer, hemorrhoids, infertility and prostatitis.

The fruits of *M. pomifera* are rich in flavonoids: kaempferol and isoflavone. Indeed, these compounds have an antitumor effect and are the basis of therapy in the treatment of cancer patients. *Maclura* fruits in the mentioned pathology of the human body can be used for the treatment of both malignant and benign formations. This remedy has the ability to slow down the division of cancer cells [59]. In this disease, it is used internally and externally. In particular, suppositories are used for vaginal treatment. Medicinal products from *M. pomifera* plants affect the growth of malignant neoplasms. Oncology prevention can be carried out, as well as therapy at different phases of the disease, during the progressive phase it is recommended to increase the dose of medicines.

M. pomifera medicinal products are banned for use during pregnancy, lactation, for children under 12 years of age, allergic reactions, diabetes mellitus, and concomitant use of antibiotics. In addition, the tincture should not be combined with alcoholic beverages, but it is permissible to combine it with herbal decoctions and fruit juices [36]

The wonderful properties of the named species, the possibility of use in everyday life and treatment, and high decorativeness deserve not only interest, but also the desire to have such a valuable culture on the private plot.

Conclusions

1. Seed propagation is the main one for *M. pomifera*, since its seeds are characterized by a high germination rate.

2. In the conditions of a cultivation structure, the maximum soil germination of seeds of 88% was observed in the case of sowing to a depth of 10-20 mm, and under the conditions of sowing to a depth of 60-70 mm, only 6% of the seed material germinated.

3. The growth of *M. pomifera* plants during the growing season was 24.7 cm. At the same time, intensive plant growth was observed during June - August.

4. The optimal soil mixture for the growth and development of seedlings of the studied species was a mixture of field soil and humus.

5. Laboratory seed germination was within 88-93%.

6. The experimental cultivar has sufficient decorative characteristics (crown habitus, original leaves and inflorescences) and is a promising taxon for landscape design: forming alleys, compositional groups, single-stem plantings and hedges.

7. *M. pomifera* is used in alternative and traditional medicine, as well as in cosmetology.

REFERENCES

1. Balabak A. F. (2003) Reproduction of rare fruit and berry crops: monograph. Uman: Operativa poligrafiya, 109 p.
2. Vitenko V. A., (1999) Maclura aurantiaca Nutt. in the Right-Bank Forest-Steppe of Ukraine. *Collection of scientific papers*, P. 520–522.
3. Vitenko V. A. (1999) Morphological characteristics and seed germination of Maclura aurantiaca Nutt. *Introduction of plants*, No. 3–4, P. 101–103.
4. Vitenko V. A. (2002) Comparative assessment of methods of reproduction of Maclura pomifera (Rafin.) Schneid. *Theoretical and applied aspects of plant introduction and green construction*, P. 74–76.
5. Vitenko V. A. (2002) Prospects for the introduction of Maclura pomifera (Rafin.) Schneid. in the conditions of the Ukrainian steppe. *The role of botanical gardens in the green construction of cities, resort and recreational area,* P. 40–43.
6. Vitenko V. A., (2003) Winter hardiness and frost resistance of maclura in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Ancient parks and problems of their preservation*, P. 108–112.
7. Vitenko V. A. (2003) History of the introduction of Maclura pomifera (Rafin.) Schneid in the territory of Ukraine and its use in landscaping gardens and parks. *Theoretical and applied aspects of plant introduction and green construction*, P. 24–26.
8. Vitenko V. A., (2004) Biological and ecological features of Maclura pomifera (Rafin.) Schneid. during introduction in the conditions of the Right-Bank Forest-Steppe of Ukraine: Author's abstract of candidate of agricultural sciences. Kyiv: NAU, 17 p.
9. Vitenko V. A., (2005) Biological and ecological features of Maclura pomifera (Rafin.) Schneid. during induction in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Autochthonous and introduced plants of Ukraine: collection of scientific works of the National Academy of Sciences of Ukraine, National Dendrological Park "Sofiivka*". Kyiv: Akademperiodyka, P. 171-183.
10. Vitenko V. A., (2005) Fruiting Maclura in the Right-Bank Forest-Steppe of Ukraine. Uman: Publishing house ALMI, 2006. 132 p.
11. Vlasyuk S. G. Bondarenko A. O., (2020) Fundamentals of ornamental gardening *Gardening and viticulture,* P. 351-365.
12. Gordienko M. I., Maurer V. M., Kovalevsky S. B., (2000) Methodical instructions for the study and research of forest crops. Kyiv, 101 p.
13. Zayachuk V. Ya., (2008) Dendrology: textbook. Lviv: Apriori, 656 p.
14. Zayachuk V. Ya., (2019) Dendrology: textbook. Kyiv: Vyscha Shkola, 675 p.
15. Kalinichenko O. A., (2003) Decorative dendrology: teaching aids. Kyiv: Vyscha Shkola, 199 p.
16. Kobyletska M. S., Terek O. I., (2017) Plant biochemistry: textbook. Lviv: Ivan Franko National University of Lviv, 270 p.
17. Kokhanovsky V. M., Kovalenko I. M., (2013) Decorative dendrology: textbook. Sumy: "Sumy National Agrarian University", 283 p.
18. Kokhanovsky V. M., Melnyk T. I., Kovalenko I. M., Melnyk A. V., (2020) Decorative dendrology: textbook. Sumy: FOP Tsoma S. P., 263 p.
19. Kokhno M. A., (2002) Dendroflora of Ukraine. Wild and cultivated trees and shrubs. Angiosperms. Kyiv: Publishing house "Phytosociotsentr", 448 p.
20. Kucheryavy V. V., Kucheryavy V. S., (2019) Greening of settlements, Lviv: Novyi svit- 2000, 224 p.
21. Lukashchuk G. B., (2020) Dendrology. Lviv: Lviv Polytechnic, 348 p.

22. Maurer V. M., Kushnir A. I., (2008) Methodological recommendations for the propagation of woody ornamental plants of the Botanical Garden of NUBiP of Ukraine. Kyiv: NUBiP, 55 p.
23. Mezhensky V. M., Mezhenska L. O., Yakubenko B. E., (2014) Non-traditional berry crops: recommendations for selection and propagation. Kyiv: CP "Komprint", 119 p.
24. Mezhensky V. M., (2018) Fundamentals of scientific research in horticulture. Calculations in Microsoft Excel. Kyiv: Lira-K, 212 p.
25. Sikura A. O., (2002) Seed propagation of Maclura pomifera (Rafin.) Schneid. in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Introduction of plants,* No. 1, P. 77–85.
26. Sudarikova Yulia., (2019) Exotic trees, bushes and lianas in the landscapes of Ukraine. Kyiv, 336 p.
27. Eresinska M., (1982) Regulation of cellular energy metabolism. *Membr. Biol*,. 70, No. 1, P. 1 – 14.
28. Hochachka P. W., (1984) Biochemical adaptation. Princeton Univ. Press, 537 p.
29. Szabla K., Pabian R., (2003) Container nursery. New technologies and techniques in forest nursery. Warsaw: State Forest Information Center, 212 p.
30. Vitenko, V. A., (2001) Evaluation of the success of the introduction of Maclura pomifera (Raf.) *Schneid in the conditions of the Right-Bank Forest-Steppe of Ukraine. Introduction of plants,* N. 3-4, P. 31–36.
31. Vitenko V. A., (2000) Comparison of growth and development of Maclura pomifera (Raf.) Schneid. in the National Botanical Garden named after M. M. Grishko of the NAS of Ukraine and the Synytsky Arboretum of the Uman Forestry Department by modeling method. *Introduction of plants,* No. 2, P. 127-129. [Electronic resource] Access mode: http://nbuv.gov.ua/UJRN/IR_2000_2_29.
32. Vitenko V. A., (2001) Assessment of the success of the introduction of Maclura pomifera (Raf.) Schneid in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Introduction of Plants*, No. 3-4, P. 31-36 [Electronic resource] Access mode: http://nbuv.gov.ua/UJRN/IR_2001_3-4_5.
33. Vitenko V. A., (2002) Seed propagation of Maclura pomifera (Raf.) Schneid. in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Introduction of Plants,* No. 1. P. 77-82. [Electronic resource] Access mode: http://nbuv.gov.ua/UJRN/IR_2002_1_13
34. Vitenko V. A., Shlapak V. P., (2006) Results of the introduction of Maclura pomifera (Rafin.) Schneid in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Introduction of Plants,* No. 1, P. 17-22. [Electronic resource] Access mode: http://nbuv.gov.ua/UJRN/IR_2006_1_4.
35. *Maclura pomifera* [Electronic resource] Access mode: https://aquagradus.com/uk/adamovo-yabloko-maklyura-recepty-nastoek-i-ih-lechebnye-svojstva?srsltid.
36. Therapeutic properties of *Maclura pomifera* [Electronic resource] Access mode: https://fitomarket.com.ua/ua/fitoblog/makljura-adamovo-jabloko-i-ee-lechebnie-svojstva.

AGROTECHNOLOGICAL AND ECONOMIC ASPECTS OF CULTIVATING MEDICINAL PLANTS IN EUROPEAN COUNTRIES: COMPARATIVE ANALYSIS AND DEVELOPMENT PROSPECTS

Horbas Serhii
Candidate of Agricultural Sciences, Associate Professor of the Department of Horticulture and Forestry, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0003-3768-8833

Kytaihora Anton
PhD Student, Department of Horticulture and Forestry, Assistant, Department of Horticulture and Forestry, Sumy National Agrarian University, Ukraine
ORCID ID: 0009-0008-0459-3508

Koval Serhii
PhD Student, Department of Horticulture and Forestry, Sumy National Agrarian University, Ukraine
ORCID ID: 0009-0004-4678-3298

Introduction

Medicinal plants play a significant role in modern medicine, the pharmaceutical industry, and traditional healthcare systems. They serve as a source of biologically active compounds widely used in the production of medicinal products, cosmetics, and dietary supplements. Due to the growing demand for natural products, interest in the cultivation of medicinal plants has been steadily increasing.

Europe is characterized by considerable diversity in natural and climatic conditions, which determines the specific features of cultivating medicinal crops in different regions. Climate, soil resources, moisture availability, and the length of the growing season directly affect plant productivity and the accumulation of active compounds. Therefore, cultivation technologies may differ significantly even within the same climatic zone [18; 23].

Ukraine, Poland, and Germany belong to the temperate climatic zone, which generally provides favorable conditions for the cultivation of a wide range of medicinal plants. However, each of these countries has its own specific agro-climatic resources and level of agricultural development, which determine the organization of production and the overall efficiency of the sector.

In Ukraine, the medicinal plant sector is characterized by significant natural potential and biodiversity, but it requires modernization and the implementation of advanced technologies. In Poland, there is active development of organic production and an export-oriented approach. Germany, in turn, is distinguished by a high level of technological advancement, standardization, and close integration with the pharmaceutical industry [24; 21].

The aim of this study is a comprehensive analysis of agrotechnological, climatic, and economic aspects of medicinal plant cultivation in European countries (using Ukraine, Poland, and Germany as examples), as well as the identification of key factors for improving production efficiency and substantiating development prospects for the sector.

To achieve this aim, the following research objectives were defined:

The objectives of the study include analyzing the impact of climatic conditions on the growth, development, and productivity of medicinal plants; investigating the specific features of medicinal plant cultivation in Ukraine; characterizing the current state and organizational-technological approaches in Poland; analyzing the high-tech model of production in Germany; conducting a comparative analysis of sector development; evaluating economic efficiency based on cost, profit, and profitability indicators; determining the impact of technological development on economic outcomes; examining the role of processing in value creation; analyzing the importance of organic production; assessing the role of state support; identifying key risks; and substantiating strategic directions for improving economic efficiency in Ukraine.

Climatic factors and their impact on medicinal plants. An important aspect of the influence of climatic conditions is the interaction between temperature regimes and soil moisture, which directly determines the intensity of physiological and biochemical processes in plants. The optimal combination of these factors ensures active root system development, improves nutrient uptake efficiency, and contributes to high productivity of medicinal crops.

Seasonal dynamics of climatic indicators are also of great importance, as they regulate the progression of phenological stages of plant development. Clearly defined seasonal patterns contribute to the harmonious progression of germination, vegetation, flowering, and fruiting processes. However, disruptions in seasonal rhythms caused by climate change may lead to desynchronization of biological processes and reduced productivity.

Special attention should be paid to microclimatic conditions, which are formed under the influence of local factors such as topography, hydrological features, soil cover, and vegetation. Even within a single climatic zone, these factors can create significant differences in temperature and moisture regimes, which must be considered when placing medicinal plant crops.

Climatic conditions largely determine technological approaches to cultivation. In regions with moisture deficits, irrigation and water-saving technologies become necessary, whereas in areas with excessive moisture, measures aimed at improving soil aeration and protecting plants from pathogens are required. Thus, climate acts as a key factor in shaping adaptive agrotechnologies.

It should also be noted that climatic conditions influence species composition and biodiversity of medicinal plants. Different climatic regions form specific phytocenoses characterized by species adapted to particular ecological niches. This determines both the diversity of medicinal raw materials and differences in their chemical composition and pharmacological activity.

Under modern conditions, the use of innovative technologies for monitoring climatic parameters is gaining increasing importance. The application of digital monitoring systems, geographic information technologies, and predictive models enables real-time analysis of climate changes and their impact on crop production. This creates conditions for improving the efficiency of medicinal plant cultivation and ensuring the stability of agricultural production under global climate transformations.

For a deeper understanding of the influence of natural conditions on the development of medicinal plants, it is advisable to examine in detail the main climatic factors and their role in shaping plant productivity. Each of these factors affects physiological processes–from seed germination to the accumulation of biologically active compounds. Summarizing these relationships makes it possible to determine the optimal conditions for producing high-quality medicinal raw materials (Table 1).

Table 1. Influence of Key Climatic Factors on Medicinal Plants

Climatic Factor	Impact on Plants	Consequences
Temperature	Regulates growth and development	Acceleration or inhibition of growth
Precipitation	Ensures water balance	Increase or decrease in yield
Light	Affects photosynthesis	Accumulation of biomass and active compounds
Air humidity	Determines conditions for disease development	Risk of fungal infections
Wind	Affects the physical condition of plants	Damage or improved aeration

The analysis of the main climatic factors shows that each of them has a complex and interrelated impact on the growth and development of medicinal plants. Temperature determines the rate of biological processes, precipitation ensures water balance, and light influences photosynthesis and the accumulation of active compounds. At the same time, air humidity and wind shape the conditions for the development or suppression of diseases and affect the physical condition of plants. Therefore, the optimal combination of these factors is a necessary condition for achieving high yields and obtaining high-quality medicinal raw materials.

To assess the specifics of medicinal plant cultivation in different countries, it is important to conduct a comparative analysis of their climatic conditions. Ukraine, Poland, and Germany belong to the temperate climatic zone; however, they differ significantly in terms of temperature regimes, precipitation levels, and humidity. The systematization of these indicators in tabular form makes it possible to clearly trace how the climatic features of each country influence agrotechnologies and risks in the cultivation of medicinal crops (Table 2).

Table 2. Comparison of climatic influence in Ukraine, Poland, and Germany

Factor	Ukraine	Poland	Germany
Temperature	High amplitude	Moderate	Mild
Precipitation	Uneven	Sufficient	Evenly distributed
Humidity	Medium	Moderate	High
Light regime	High solar radiation	Medium	Moderate
Risks	Droughts, frosts	Periodic fluctuations	High humidity, diseases

A comparative analysis of the climatic conditions of Ukraine, Poland, and Germany indicates significant differences in the natural prerequisites for the cultivation of medicinal plants. Ukraine is characterized by a more continental climate with increased risks of droughts and temperature fluctuations, Poland demonstrates relative stability and sufficient moisture supply, while Germany is distinguished by a mild and humid climate with an elevated risk of plant diseases. Therefore, the efficiency of medicinal crop cultivation in each country depends on the adaptation of agrotechnologies to specific climatic conditions.

Climatic conditions are among the most important factors determining the efficiency of medicinal plant cultivation. Temperature, humidity, precipitation, light regime, and wind conditions directly affect plant growth, development, and the accumulation of biologically active compounds.

The comparative analysis showed that Ukraine is characterized by a more continental climate with increased risks of droughts and temperature fluctuations. Poland has more stable conditions with sufficient moisture, which contributes to consistent yields. Germany is characterized by a mild and humid climate that provides favorable growing conditions but requires careful phytosanitary control of plants [18].

Thus, climatic conditions form the basic prerequisites for the cultivation of medicinal plants; however, their impact is realized through specific agrotechnologies and organizational approaches that differ depending on the country. In this regard, it is advisable to consider in more detail the features of medicinal plant cultivation in each of the studied countries.

Taking into account the above-mentioned climatic features, it is appropriate to first analyze the specifics of medicinal plant cultivation in Ukraine as a country with high natural potential [10; 13].

Features of medicinal plant cultivation in european countries

Ukraine has significant potential for the development of medicinal plant cultivation due to favorable natural and climatic conditions, advantageous geographical location, and high biodiversity. Different natural zones–Polissia, Forest-Steppe, and Steppe–form a wide range of ecological niches, creating favorable conditions for cultivating various medicinal plant species with different biological requirements.

One of the characteristic features of the sector is the combination of cultivated and wild-growing medicinal plants. A significant share of medicinal raw materials is still harvested from natural habitats, which reduces production costs but simultaneously creates risks of depletion of natural populations and necessitates the implementation of sustainable resource management principles.

The climatic conditions of Ukraine favor the cultivation of many traditional medicinal plants, including chamomile, peppermint, St. John's wort, valerian, and calendula. Warm summers, sufficient solar radiation, and a long growing season ensure the intensive synthesis of biologically active compounds, thereby increasing the pharmacological value of raw materials.

At the same time, the uneven distribution of precipitation creates certain challenges for agricultural producers. Frequent droughts in southern and eastern regions can significantly reduce yields, which necessitates the implementation of irrigation systems, the use of drought-resistant varieties, and the optimization of cultivation technologies.

The soil cover of Ukraine, particularly chernozems, is characterized by high natural fertility, creating favorable conditions for cultivating medicinal plants with minimal use of mineral fertilizers. This opens up broad opportunities for the development of environmentally oriented and organic production.

The agrotechnology of medicinal plant cultivation in Ukraine is gradually improving. However, in many farms, traditional soil cultivation methods are still used, which do not always meet modern requirements for efficiency and environmental sustainability. At the same time, there is a gradual introduction of innovative technologies.

A characteristic feature is the relatively low level of mechanization of production processes compared to European Union countries. A significant proportion of operations, especially harvesting medicinal raw materials, is performed manually, which increases labor intensity and production costs.

The system of standardization and quality control of medicinal raw materials in Ukraine is at an active stage of development. Although international standards, including GACP, are being introduced, their application is not yet widespread, which affects the competitiveness of products in the international market.

Economic factors also play an important role in the development of the sector. Limited access to investment resources, insufficient technical equipment, and market instability restrain the expansion of medicinal plant production.

At the same time, there is a growing interest in organic medicinal plant production, which opens new opportunities for export and increasing added value. Ukraine has significant potential to occupy competitive positions in the European market of organic medicinal raw materials.

An important direction of development is also the regional specialization of production. In different natural and climatic zones, it is advisable to cultivate those medicinal plant species that are best adapted to local conditions, which allows increasing the efficiency of resource use.

Another important aspect is the development of scientific support for the sector. Research in the fields of breeding, agrotechnology, and pharmacognosy contributes to increasing yields, improving the quality of raw materials, and ensuring compliance with international standards.

In addition, the implementation of modern information technologies in production is becoming increasingly relevant. The use of monitoring systems, weather forecasting tools, and digital management of agricultural processes makes it possible to optimize production and reduce risks.

Special attention should be paid to the development of cooperation among producers of medicinal raw materials. The consolidation of small and medium-sized farms contributes to increased production efficiency, improved logistics, and stronger market positions [22; 23; 31].

In summary, despite the existing challenges, Ukraine has significant prospects for the development of medicinal plant cultivation. The implementation of modern agrotechnologies, improvement of standardization, development of organic production, and integration into the European market can ensure increased efficiency of the sector and its competitiveness at the international level.

Taking into account the identified features and challenges of medicinal plant cultivation in Ukraine, it is advisable to consider the experience of other European countries, particularly Poland, which demonstrates a more stable and well-organized model of sector development.

Poland is one of the leading countries in Europe in the field of medicinal plant cultivation, which is due to favorable natural and climatic conditions, effective state policy, and a high level of agricultural organization. As a result, the country occupies an important position in the European market of medicinal plant raw materials, meeting both domestic demand and ensuring significant export volumes.

The climate of Poland is moderate and transitional from maritime to continental, providing relatively stable conditions for the cultivation of most medicinal crops. Moderate temperatures, the absence of sharp climatic fluctuations, and sufficient precipitation throughout the year create favorable conditions for plant growth, development, and the accumulation of biologically active compounds. Such climatic stability minimizes the risks of yield losses and ensures predictability of production.

A wide range of medicinal plants is cultivated in Poland, among which chamomile, lemon balm, sage, valerian, and nettle occupy a prominent place. Considerable attention is also given to essential oil crops used in the pharmaceutical, cosmetic, and food industries. The diversity of crops is обусловлена both favorable natural conditions and established market demand for medicinal raw materials.

One of the key features is the high level of production organization. A significant number of farms operate under a contract system in cooperation with pharmaceutical enterprises and processing companies. This ensures stable product sales, guarantees compliance with quality standards, and reduces economic risks for producers.

Poland is actively developing organic medicinal plant production, which is an important segment of the agricultural sector. Cultivation without the use of synthetic fertilizers and pesticides makes it possible to obtain environmentally safe products that meet modern consumer requirements and have high demand in European and global markets.

An important characteristic is the high level of mechanization of production processes. The use of modern agricultural machinery and specialized equipment for sowing, cultivation, and harvesting contributes to reducing labor intensity, increasing productivity, and improving the quality of raw materials.

The system of standardization and quality control in Poland fully complies with European requirements. Producers adhere to international standards, including the principles of Good Agricultural and Collection Practices (GACP), which ensures the safety, effectiveness, and consistency of product quality.

State support plays a crucial role in the development of the sector. Agricultural producers receive financial subsidies, grants, and access to development programs that stimulate the implementation of innovative technologies and the expansion of medicinal plant cultivation.

Poland has a well-developed infrastructure for processing medicinal raw materials. A significant share of production undergoes primary and deep processing, including drying, extraction, and essential oil production. This increases the added value of products and strengthens the country's position in the international market.

An important feature of the Polish model is the close integration of medicinal plant production with scientific research. Research institutions actively work on breeding new varieties adapted to local conditions, improving productivity, and increasing the content of biologically active compounds.

In addition, considerable attention is paid to the development of cooperation among producers. The formation of farmer cooperatives contributes to more efficient use of resources, improved logistics, and stronger market positions.

Another important factor is the development of training and advisory systems for producers. Polish farmers have access to modern knowledge, technologies, and recommendations, which contributes to improving their professional competence and production efficiency [25; 52].

Overall, medicinal plant cultivation in Poland is characterized by a high level of organization, technological advancement, standardization, and export orientation. The combination of natural resources, innovative technologies, state support, and integration with the scientific sector ensures stable development and competitiveness of the industry. This experience can be effectively utilized by other countries, particularly Ukraine, to improve their own medicinal plant sector.

At the same time, an even higher level of development of medicinal plant cultivation is observed in Germany, where the sector is characterized by high technological advancement, innovation, and deep integration with the pharmaceutical industry.

Germany is one of the leading countries in Europe in the field of cultivation and processing of medicinal plants. A highly developed agricultural sector, a powerful pharmaceutical industry, and their close integration ensure the efficient functioning of the sector. This allows the country not only to meet domestic demand but also to play a significant role in the international market of medicinal plant raw materials.

The climate of Germany is predominantly temperate with a strong influence of maritime air masses, resulting in mild winters and moderately warm summers. The absence of sharp temperature fluctuations and the even distribution of precipitation throughout the year create stable conditions for plant growth, promote uniform development, and ensure the formation of high-quality raw materials.

A wide range of medicinal crops is cultivated in Germany, among which chamomile, St. John’s wort, lavender, calendula, and fennel are of particular importance. Considerable attention is also given to crops with a high content of essential oils, which are widely used in the pharmaceutical, cosmetic, and food industries. The selection of crops is based on a combination of agroecological conditions and market demand.

One of the key features is the high level of mechanization and automation of production. Modern machinery and specialized equipment are used at all stages of the production process–from soil preparation to harvesting and primary processing of raw materials. This ensures high productivity, reduces labor costs, and minimizes product losses.

Innovative agrotechnologies are widely implemented in Germany, including precision farming systems, automated irrigation, remote plant monitoring, and the use of digital platforms for agricultural management. These technologies allow for optimization of resource use, increased yields, and consistent product quality.

An important feature is the strict compliance with international quality standards, such as GACP (Good Agricultural and Collection Practices) and GMP (Good Manufacturing Practice). This ensures the safety, efficacy, and standardization of medicinal plant raw materials, which is critically important for pharmaceutical use.

The country has a well-developed quality control system at all stages of production. Seed selection, monitoring of cultivation conditions, harvesting, drying, and storage are carried out in accordance with strict regulations, which ensures a high level of trust in German products on the global market.

Germany possesses a strong research and development base that plays a key role in the advancement of the sector. Research institutions and universities are actively engaged in breeding new varieties of medicinal plants, studying their chemical composition, and improving cultivation technologies. Close cooperation between science, production, and the pharmaceutical industry facilitates the implementation of innovations.

The economic model of the sector is focused on the production of high value-added products. A significant portion of medicinal raw materials undergoes deep processing within the country, including the production of extracts, essential oils, and finished medicinal products.

A notable feature is the high level of environmental responsibility in production. Germany actively implements the principles of sustainable development, including the rational use of natural resources, reduction of environmental impact, and the development of organic farming.

An important direction is the development of cooperation and integration among market participants. Producers, processing enterprises, and research institutions operate within a unified system, which contributes to increased efficiency and rapid implementation of innovations.

In addition, considerable attention is paid to the training of qualified personnel. Educational programs and professional training ensure a high level of competence among specialists working in the medicinal plant sector [24; 21].

Thus, medicinal plant cultivation in Germany is characterized by a high level of technological development, standardization, scientific support, and innovation. The combination of modern agrotechnologies, efficient production organization, and strict quality control allows the country to occupy leading positions in Europe and provide stable, competitive products that meet the highest international standards.

The analyzed features of medicinal plant cultivation in Ukraine, Poland, and Germany provide a basis for a comparative analysis aimed at identifying key differences and efficiency factors.

Comparative analysis of development

The cultivation of medicinal plants in European countries has both common features and significant differences, determined by a combination of natural, economic, and technological factors. Ukraine, Poland, and Germany belong to the same temperate climatic zone; however, the level of development of the medicinal plant sector in these countries differs significantly, reflecting the specifics of their economic development and agricultural policies.

First of all, it should be noted that Ukraine has significant natural potential due to the high fertility of soils, particularly chernozems, and the diversity of climatic conditions. This creates favorable conditions for cultivating a wide range of medicinal crops. However, in practice, this potential is not fully realized due to insufficient technical support, limited access to investment, and slow implementation of modern agrotechnologies.

Poland occupies an intermediate position between Ukraine and Germany, combining favorable natural conditions with a relatively high level of production organization. Active state support, an effective subsidy system, and export orientation contribute to the stable development of the sector. In addition, considerable attention is paid to compliance with quality standards and the implementation of innovative technologies.

Germany, in turn, represents an example of a high-tech and intensive approach to the cultivation of medicinal plants. The sector is closely integrated with the pharmaceutical industry, ensuring a full production cycle–from the cultivation of raw materials to the manufacturing of finished medicinal products. This enables the creation of high value-added products and ensures their competitiveness on the global market.

An important aspect is also the level of mechanization and automation of production. While in Ukraine a significant share of work is performed manually, Poland demonstrates a medium level of mechanization, whereas in Germany most technological processes are fully automated. This directly affects labor productivity, production costs, and product quality.

Significant differences are also observed in quality control systems. In Germany and Poland, international standards such as GACP and GMP are widely implemented, ensuring high-quality medicinal raw materials. In Ukraine, these standards are only gradually being introduced, which limits the potential for exporting products to the European market.

Special attention should be given to the role of state support. In European Union countries, particularly in Poland and Germany, the agricultural sector receives substantial financial support, which stimulates the development of medicinal plant cultivation. In Ukraine, however, state support is less systematic, which restrains the modernization of the sector.

An important direction is the development of organic medicinal plant production. In Poland and Germany, this segment is actively developing and has significant export potential. Ukraine also has favorable conditions for the development of organic production; however, this direction requires further institutional and technological support.

No less important is the level of scientific support for the sector. In Germany, scientific research is an integral part of the production process; in Poland, it is actively implemented in practice, whereas in Ukraine, scientific potential is not utilized efficiently enough.

Another important aspect is the dynamics of sector development in recent years. Changes in cultivation areas, production volumes, and export levels reflect the general trends in the development of the sector in each country. In EU countries, there is a tendency toward stable or gradual growth of cultivation areas due to state support and high demand for products. In Ukraine, these indicators are more unstable and depend on the economic situation and investment activity.

For a more detailed analysis, it is advisable to examine the dynamics of cultivation areas of medicinal plants in the studied countries, which will make it possible to assess development trends, identify patterns, and determine prospects for further growth of the sector (Table 3).

Table 3. Dynamics of cultivation areas of medicinal plants (2019–2024), thousand hectares

Year	Ukraine	Poland	Germany
2019	32	28	15
2020	30	29	16
2021	27	30	17
2022	25	31	18
2023	26	32	19
2024	28	34	20

During the period 2019–2024, Ukraine experienced a decline in cultivation areas, particularly in 2020–2022, which is associated with economic challenges and climatic risks.At the same time, Poland and Germany demonstrate a steady increase in cultivation areas, indicating effective sectoral support and stable development conditions.

Another important indicator is the volume of medicinal raw material production, which reflects the efficiency of resource utilization and the level of technological development (Table 4).

Table 4. Production volumes of medicinal plants (2019–2024), thousand tons

Year	Ukraine	Poland	Germany
2019	45	50	40
2020	43	52	42
2021	40	55	45
2022	38	57	47
2023	41	60	50
2024	44	63	53

The analysis of the data for 2019–2024 shows that Poland occupies leading positions in terms of production volumes among the studied countries, while Germany demonstrates steady growth due to high productivity. In Ukraine, however, certain instability in production indicators can be observed.

Another important criterion is the level of yield, which reflects the efficiency of cultivation technologies and the quality of agrotechnical practices.

Therefore, the analysis of yield indicators provides a deeper understanding of the effectiveness of resource use and technological development in medicinal plant cultivation (Table 5).

Table 5. Average yield of medicinal plants (2019–2024), centners per hectare

Year	Ukraine	Poland	Germany
2019	14	18	22
2020	14	19	23
2021	13	20	24
2022	12	21	25
2023	13	22	26
2024	14	23	27

The presented data for 2019–2024 indicate that Germany demonstrates the highest yield levels, which can be explained by the use of advanced technologies and a high level of mechanization. Poland also shows a positive trend, while Ukraine lags behind in this indicator.

Thus, the comparative analysis shows that Ukraine has significant potential for the development of medicinal plant cultivation but requires modernization and the implementation of innovations. Poland serves as an example of an effective combination of natural resources and modern technologies, while Germany represents a leader in high-tech production and standardization. Further development of the sector in Ukraine is possible through the adaptation of European experience, increased investment, and improvement of quality management systems.

Alongside natural and technological aspects, economic evaluation of production is of great importance, as it allows for determining the efficiency of resource use and the feasibility of sector development.

Economic efficiency of medicinal plant cultivation

An important aspect of assessing the development of medicinal plant cultivation is the determination of its economic efficiency. The comparison of not only natural and technological conditions but also economic indicators allows for a more comprehensive evaluation of the level of sector development in the studied countries.

The economic efficiency of medicinal plant cultivation is one of the key indicators determining the feasibility of developing this sector within agriculture. It reflects the relationship between production costs and the results obtained in the form of profit, profitability, and added value.

Under modern economic conditions, efficiency is determined not only by economic indicators but also by environmental and social aspects. The cultivation of medicinal plants is often associated with the use of environmentally friendly technologies, which increases their market value but may also influence the cost structure.

The main indicators of economic efficiency include production cost, profitability level, profit per unit area, labor productivity, and the level of added value.

The costs of cultivating medicinal plants have a complex and multi-component structure and depend on several factors, including the biological characteristics of the crop, cultivation technology, the level of mechanization, and the natural and climatic conditions of a particular region. Cost formation occurs at all stages of the production process–from soil preparation to harvesting, processing, and product marketing.

Material costs constitute a significant share of the total production cost. These include expenses for seeds or planting material, which may vary considerably depending on the type and variety of medicinal plants. An important component is also the cost of mineral and organic fertilizers, which ensure optimal plant nutrition and contribute to increased yields. Plant protection products are used to control pests, diseases, and weeds, particularly in intensive production systems. A separate share of costs includes fuel and lubricants used in mechanized field operations.

Labor costs are one of the most significant components in medicinal plant cultivation. They include wages for manual labor, which is especially relevant during plant care and harvesting stages. Many medicinal crops require manual harvesting to preserve raw material quality, which significantly increases labor intensity. In addition, labor costs include payments to qualified specialists such as agronomists, technologists, and quality control personnel.

Technical costs are associated with the use of agricultural machinery and equipment. These include operating expenses and depreciation costs related to maintenance and renewal. The level of technical costs largely depends on the degree of mechanization: in high-tech farms, these costs are higher but are offset by increased labor productivity.

Other costs include expenses for irrigation (especially in regions with insufficient moisture), drying and primary processing of medicinal raw materials, and transportation to storage or marketing points. Energy costs, packaging, and storage also play a significant role.

A specific feature of medicinal plant cultivation is the high level of labor intensity, especially during harvesting, which is due to the need to maintain the quality and integrity of plant raw materials. In many cases, the use of mechanized harvesting is limited due to the risk of damage or reduction in pharmacological value.

In addition, the cost structure is significantly influenced by the scale of production and the level of specialization. Large farms benefit from economies of scale, which reduce unit costs, while small farms often face higher costs due to limited access to modern equipment and resources.

An important factor is also the type of production–conventional or organic. Organic cultivation of medicinal plants is usually associated with higher costs due to restrictions on the use of chemical inputs and the need for alternative plant care methods. However, such products have a higher market value, which can compensate for increased costs.

Thus, the cost structure in medicinal plant cultivation is complex and depends on many interrelated factors. Its optimization is an important condition for increasing economic efficiency, which can be achieved through the implementation of modern technologies, increased mechanization, and rational use of resources.

Production cost is one of the key economic indicators that characterizes the efficiency of medicinal plant cultivation. It reflects the total expenses required to produce a unit of output and serves as the basis for pricing and determining the profitability of the sector.

The formation of the cost of medicinal plant raw materials depends on a complex set of factors, among which the biological characteristics of the crop, yield level, applied agrotechnologies, natural and climatic conditions, and production organization are of particular importance. The degree of mechanization and the use of modern technical equipment also have a significant impact.

One of the key factors in reducing production costs is increasing yield. Under equal costs per unit area, an increase in output leads to a reduction in unit production costs. However, achieving high yields often requires additional expenditures on fertilizers, plant protection products, and technological measures, which necessitates cost optimization.

Labor costs constitute a significant share in the cost structure of medicinal plant production, especially when harvesting is performed manually. This is a distinctive feature of the sector compared to conventional crop production. High labor intensity may lead to increased production costs, particularly under conditions of rising labor expenses.

The level of technological support also has a considerable impact on production costs. The use of modern machinery and innovative technologies allows for reducing labor costs, improving resource efficiency, and minimizing production losses. However, the implementation of such technologies requires significant investment, which may increase initial costs.

Production scale is another important factor. In large-scale farms, production costs are generally lower due to economies of scale, more efficient resource utilization, and the ability to implement advanced technologies. In small-scale farms, unit costs are often higher, which reduces their competitiveness.

The level of product processing also plays a significant role. The production of primary raw materials is characterized by lower added value, whereas further processing (drying, extraction, essential oil production) significantly increases economic efficiency and reduces dependence on market fluctuations.

The profitability of medicinal plant cultivation is an integral indicator reflecting the relationship between profit and costs. It allows for assessing the feasibility and efficiency of production. High profitability indicates efficient resource use and product competitiveness.

The level of profitability largely depends on market price conditions, product quality, and the level of processing. In countries with a well-developed processing industry, such as Germany, profitability is higher due to the production of high value-added products. In Poland, profitability is supported by state support and effective production organization.

In Ukraine, profitability is less stable and depends on various factors, including climatic conditions, access to investment, and the level of technological development. At the same time, favorable natural conditions create opportunities for increasing sector profitability, provided that production modernization is implemented.

An important direction for increasing profitability is the development of organic medicinal plant production. Organic products have a higher market price, which allows compensating for increased production costs. In addition, they enjoy stable demand on the international market.

Thus, production cost and profitability of medicinal plant cultivation are interrelated indicators that determine the economic efficiency of the sector. Their optimization requires a comprehensive approach, including the implementation of modern technologies, increased mechanization, development of processing, and adaptation of production to market requirements.

For the economic evaluation of medicinal plant cultivation, it is advisable to use a system of generalized indicators (Table 6) that make it possible to determine the level of costs, profit, and production efficiency. The main indicators include total production cost, unit cost, profit, and profitability level.

Total production cost is defined as the sum of all expenses associated with cultivation, harvesting, drying, primary processing, and transportation of products:

1. Total production cost:

$$Cp = Cm + Cl + Ct + Co$$

where: Cp – total production cost, UAH; Cm – material costs, UAH; Cl – labor costs, UAH; Ct – technical costs, UAH; Co – other costs, UAH.

2. Unit cost of production:

$$Cu = Cp / Q$$

where: Cu – unit cost, UAH/t; Cp – total production cost, UAH; Q – production volume, t.

3. Revenue:

$$R = Q \times P$$

where: R – revenue, UAH; Q – volume of sold products, t; P – price per ton, UAH.

4. Profit:

$$Pr = R - Cp$$

where: Pr – profit, UAH; R – revenue, UAH; Cp – total production cost, UAH.

5. Profitability level:

$$Prof = (Pr / Cp) \times 100\%$$

where: Prof – profitability level, %; Pr – profit, UAH;Cp – total production cost, UAH.

The use of these formulas allows for a comprehensive assessment of the economic efficiency of medicinal plant cultivation. The calculation of total cost, unit cost, revenue, profit, and profitability provides an objective basis for evaluating production performance and identifying key factors influencing efficiency.

These indicators serve as an important tool for economic analysis, enabling both the assessment of current production conditions and the justification of management decisions aimed at cost optimization, productivity improvement, and quality enhancement. This is particularly relevant in a market economy, where competitiveness depends on achieving an optimal balance between costs and results.

Furthermore, the analysis of cost and profitability allows for comparison of different medicinal crops, identification of the most profitable production directions, and development of strategic approaches for sector advancement. This is especially important for Ukraine, which possesses significant natural potential but requires improvements in technological development and resource efficiency.

Thus, the systematic application of economic calculations is essential for increasing efficiency, ensuring sustainable development, and integrating medicinal plant cultivation into the international market.

Table 6. Example of calculating the cost and profitability of medicinal plant cultivation

Indicator	Nominal value
Cultivation area, ha	10
Yield, t/ha	2.5
Gross output, t	25
Material costs, UAH	180,000
Labor costs, UAH	120,000
Technical costs, UAH	90,000
Other costs, UAH	60,000
Total production cost, UAH	450,000
Selling price per 1 t, UAH	25,000
Sales revenue, UAH	625,000
Profit, UAH	175,000
Unit cost per 1 t, UAH/t	18,000
Profitability, %	38.9

In the presented example, the cultivation area of medicinal plants is 10 hectares, and the average yield is 2.5 t/ha, resulting in a gross output of 25 tons of products. The total production cost amounts to UAH 450,000, with the largest share consisting of material and labor costs.

Given a selling price of UAH 25,000 per ton, total revenue amounts to UAH 625,000. Accordingly, profit equals UAH 175,000. The unit cost of production is UAH 18,000 per ton, and the profitability level is 38.9%, which indicates a relatively high level of economic efficiency.

The presented example is conditional; however, it demonstrates the general approach to the economic evaluation of medicinal plant cultivation. In real conditions, the values of indicators may vary depending on the type of crop, growing region, weather conditions, technological support, and market price.

The use of cost, profit, and profitability formulas makes it possible to objectively assess the economic efficiency of medicinal plant cultivation. Such calculations are an important tool for managerial decision-making, cost planning, determining the feasibility of cultivating specific crops, and increasing overall sector profitability.

Economic efficiency directly depends on the level of technological support in production, which necessitates a detailed analysis of the impact of modern technologies.

Factors increasing efficiency

Technological development is one of the key factors in increasing the economic efficiency of medicinal plant cultivation. The level of implementation of modern agrotechnologies directly affects production productivity, product quality, cost levels, and the competitiveness of the sector in both domestic and international markets.

The introduction of innovative technologies allows for optimization of all stages of the production process–from soil preparation to harvesting and primary processing of medicinal raw materials. This ensures more rational use of material, labor, and technical resources, ultimately contributing to reduced production costs and increased profitability.

The main advantages of modern technologies include reduced resource consumption through precise application of inputs, increased yields, improved product quality, reduced losses during harvesting and storage, and decreased labor costs due to automation.The implementation of precision agriculture technologies is of particular importance. These include the use of digital monitoring systems, GPS navigation, sensor technologies, and data analytics. Such approaches allow for accounting for soil heterogeneity, optimizing the application of inputs, and improving land-use efficiency.

In Germany, precision agriculture is widely applied and significantly increases the efficiency of medicinal plant production. Automated management systems, modern machinery, and a high level of digitalization ensure stable yields and high product quality.

In Poland, automated cultivation systems are actively implemented, including modern seeders, irrigation systems, and mechanized harvesting. This reduces labor intensity and increases production efficiency, although the technological level is somewhat lower than in Germany.

In Ukraine, the process of technological modernization is still developing. Many farms continue to use traditional cultivation methods, which limits productivity and efficiency. However, gradual implementation of modern technologies, including irrigation systems, elements of precision agriculture, and improved plant varieties, is being observed.

An important aspect is also the impact of technological level on environmental sustainability. Modern technologies make it possible to reduce negative environmental impacts by decreasing the use of chemicals, optimizing water consumption, and implementing resource-saving technologies. This is especially relevant in the context of the development of organic medicinal plant production.

In addition, technological development contributes to increased production stability. The use of modern weather forecasting systems, plant monitoring, and risk management tools helps minimize the impact of adverse factors and ensures more predictable production outcomes.

Thus, the level of technological support is one of the key determinants of the economic efficiency of medicinal plant cultivation. The implementation of innovative agrotechnologies, increased mechanization, and digitalization create conditions for higher productivity, lower costs, and improved competitiveness of the sector.

Alongside technological development, the level of product processing is also an important factor influencing economic efficiency.

One of the key factors in increasing the economic efficiency of medicinal plant cultivation is the level of product processing. It is the degree of processing that determines the amount of added value generated at each stage of the production chain–from plant cultivation to the final pharmaceutical product.

Several levels of medicinal plant processing can be distinguished, including raw materials as the lowest value category, dried products as a form of primary processing, extracts and essential oils as products of deeper processing, and finished medicinal products representing the highest level of value creation represent the highest level of processing, ensuring maximum economic benefit due to the high market value of the final product.

An increase in the level of processing directly contributes to higher economic efficiency. The transition from selling raw materials to deep processing not only increases profit but also reduces dependence on raw material price fluctuations, which is an important factor for sector stability.

In Germany, most medicinal plant products undergo deep processing within the country. This ensures the formation of high added value, supports the development of the pharmaceutical industry, and strengthens the country's position in the international market. The production process is highly integrated, allowing quality control at all stages and ensuring compliance with international standards.

In Poland, there is also active development of processing infrastructure, particularly in drying, extraction, and essential oil production. This contributes to increased competitiveness and export orientation of production.

In Ukraine, however, the export of medicinal plant raw materials without sufficient processing predominates, significantly limiting the potential for value-added creation. As a result, a considerable share of profits is generated outside the country, where further processing takes place.

An important direction for improving economic efficiency in Ukraine is the development of processing capacities, including the establishment of enterprises for the production of extracts, essential oils, and finished medicinal products. This will not only increase producers' income but also stimulate the development of related industries, job creation, and overall economic growth [8; 9; 31; 44].

Thus, the level of processing of medicinal plants is one of the key factors in the formation of added value and economic efficiency. Deepening product processing is an important strategic direction for the development of medicinal plant cultivation, especially for countries with high natural potential, such as Ukraine.

A separate promising direction for improving efficiency is the development of organic medicinal plant production.

Organic medicinal plant cultivation is one of the most promising directions in the modern agricultural sector, driven by increasing demand for environmentally friendly products and stricter requirements for the quality of medicinal raw materials. Cultivation under organic standards involves refusal from the use of synthetic fertilizers, pesticides, and other chemicals, which contributes to environmental protection and improved product safety.

The economic advantages of organic production include higher product prices, growing demand in domestic and international markets, access to European markets, and increased competitiveness due to compliance with international standards.

An important feature of organic medicinal plant cultivation is its close connection with the principles of sustainable development. The use of environmentally safe technologies contributes to preserving soil fertility, biodiversity, and natural resources, which has long-term economic significance.

In Poland and Germany, organic medicinal plant production is actively supported by the state through subsidies, grants, and development programs. This encourages producers to transition to organic technologies and expand production volumes. In addition, these countries have established effective certification and quality control systems.

In Ukraine, organic medicinal plant cultivation is still in the development stage. Despite significant natural potential and favorable conditions for environmentally friendly production, its development is constrained by limited access to financing, insufficient institutional support, and difficulties in entering international markets.

The prospects for the development of organic medicinal plant production in Ukraine are associated with integration into the European market, improved standardization, and the implementation of modern technologies. The expansion of this segment will increase economic efficiency, boost exports, and strengthen the position of Ukrainian producers in the global market [6; 41; 20].

Thus, organic medicinal plant cultivation is an important direction for increasing economic efficiency, combining economic benefits with environmental sustainability and aligning with modern trends in agricultural development.

An important institutional factor in the development of the sector is state support.

State support is one of the key factors ensuring the economic efficiency of medicinal plant cultivation. It creates favorable conditions for sector development, stimulates investment activity, promotes the implementation of innovative technologies, and enhances the competitiveness of products in both domestic and international markets.

In European Union countries, state support for medicinal plant cultivation is implemented through a set of instruments, including:

State support is implemented through a range of instruments, including subsidies, grants, cost compensation mechanisms, and long-term development programs aimed at modernizing the agricultural sector.

Thanks to such a support system, conditions for stable development of medicinal plant cultivation are created in EU countries. Producers are able to reduce financial risks, implement modern technologies, and focus on producing high value-added products.

In Germany, state support is closely linked with scientific research and innovation, enabling the integration of medicinal plant production with the pharmaceutical industry. In Poland, European funds play a significant role, being directed toward the development of organic production, modernization of the technical base, and improvement of product quality.

In Ukraine, state support for medicinal plant cultivation remains limited and lacks a systemic character. Existing programs often do not account for the specific features of this sector or suffer from insufficient funding. This complicates the implementation of modern technologies, restrains the development of processing, and reduces the investment attractiveness of the industry.

Moreover, the absence of a clear state strategy for the development of medicinal plant cultivation leads to fragmented support measures and insufficient coordination between producers, research institutions, and processing enterprises. This negatively affects the overall efficiency and competitiveness of the sector.

At the same time, Ukraine has significant potential to improve its system of state support. The introduction of comprehensive development programs, stimulation of investment, support for organic production, and integration into European markets can substantially improve the situation.

In conclusion, state support acts as a decisive factor in shaping the economic efficiency of medicinal plant cultivation, and its consistency and scale directly influence the level of sector development and its competitive position in the international market.

The generalization of the identified trends makes it possible to determine the main directions for increasing economic efficiency in the sector.

Improving the economic efficiency of medicinal plant cultivation is one of the key tasks for sector development under modern conditions. It requires a comprehensive approach that encompasses both technological and organizational-economic aspects of production.

To achieve a high level of efficiency, it is necessary to implement modern agrotechnologies, develop processing of medicinal plant raw materials, support organic production, integrate into European markets, and promote cooperation among producers.

A comparative analysis of the economic efficiency of medicinal plant cultivation in different countries makes it possible to identify key factors determining sector competitiveness. Ukraine, Poland, and Germany share similar natural conditions but differ significantly in the level of economic organization and technological development.

In Ukraine, medicinal plant cultivation is predominantly extensive in nature. Production is mainly focused on raw materials with minimal processing, which limits the formation of high added value. In addition, insufficient mechanization, limited access to investment, and market instability hinder sector development and reduce efficiency.

Poland demonstrates a more balanced development model, combining favorable natural conditions, state support, and modern production organization. The active implementation of technologies, development of organic production, and export orientation ensure a stable level of economic efficiency.

Germany represents a highly efficient economic model based on innovation, automation, and deep product processing. Production processes are characterized by a high level of technological advancement, while close integration with the pharmaceutical industry ensures the creation of maximum value-added products.

In this context, the key directions for improving the efficiency of medicinal plant cultivation in Ukraine include production modernization, development of processing infrastructure, implementation of innovative technologies, and strengthening of state support. An important role is also played by adaptation to international quality standards and expansion into foreign markets [13; 43; 55].

Summarizing the above, it can be stated that increasing the economic efficiency of medicinal plant cultivation requires a systemic approach that combines technological development, organizational transformation, and active integration into the international economic environment, ensuring sustainable sector growth and competitiveness.

The economic efficiency of medicinal plant cultivation largely depends on the level of risks associated with the production process. The presence of various risks may lead to reduced yields, deterioration of product quality, increased costs, and instability of producers' income.

The main risks in medicinal plant cultivation include climatic, market, technological, and financial risks, each of which can significantly affect production efficiency and stability.

In addition, organizational risks related to imperfect production management and institutional risks caused by instability of the regulatory framework are also important.

In Ukraine, the level of risks in medicinal plant production is significantly higher than in European Union countries. This is due to greater dependence on climatic conditions, insufficient agricultural insurance systems, limited state support, and unstable market environments.

In Poland and Germany, risks are largely minimized due to the use of modern technologies, developed insurance systems, effective state support, and stable economic policies. Moreover, producers have better access to information resources, weather forecasts, and market analytics, allowing for more effective risk management.

An important direction for improving economic efficiency is the implementation of risk management systems, including production diversification, the use of insurance instruments, the adoption of modern technologies, and adaptation to climate change. This helps to reduce the negative impact of risks and ensure production stability.

Summarizing the above, it should be emphasized that the level of risks is one of the key determinants of the economic efficiency of medicinal plant cultivation. Their timely identification and minimization create the necessary conditions for stable sector development and increased competitiveness.

The development of medicinal plant cultivation in Ukraine requires the definition of clear strategic priorities aimed at improving economic efficiency, competitiveness, and integration into the global market. In the context of growing demand for medicinal plant raw materials and plant-based products, the formation of a long-term development strategy becomes particularly important.

The key directions for Ukraine's development include:

- the development of processing of medicinal plant raw materials, enabling the transition from raw material exports to the production of high value-added products, including extracts, essential oils, and finished medicinal products;
- attraction of investments necessary for production modernization, upgrading of technical infrastructure, implementation of innovative technologies, and development of processing capacities;
- improvement of the standardization and quality control system, particularly through the implementation of international standards (GACP, GMP), which is essential for access to European markets and increasing trust in Ukrainian products;
- strengthening of state support, including financial incentives, development programs for producers, export promotion, and the creation of a favorable institutional environment.
- In addition to these directions, the development of the research and innovation base is of great importance, as it enables the creation of new medicinal plant varieties adapted to Ukrainian conditions and the improvement of cultivation technologies. The development of cooperation among producers, processing enterprises, and research institutions also plays a significant role in improving resource efficiency.

Another important strategic direction is the development of organic medicinal plant production, which has significant export potential and corresponds to modern trends in agricultural development. The use of environmentally friendly technologies will enhance the competitiveness of Ukrainian products in the international market.

Furthermore, an essential condition for sector development is integration into international markets, which involves harmonization of standards, participation in international programs, and expansion of export opportunities. This will allow Ukrainian producers to strengthen their position in the global market for medicinal plant products [50; 37].

It is important to emphasize that the implementation of strategic directions for the development of medicinal plant cultivation in Ukraine requires a comprehensive approach that combines technological modernization, institutional support, and active integration into the global economic space. This will ensure sustainable sector growth and increased economic efficiency.

Conclusions

The conducted research presented in this monograph made it possible to comprehensively analyze the agrotechnological, climatic, and economic features of medicinal plant cultivation in European countries, particularly in Ukraine, Poland, and Germany. The obtained results indicate that medicinal plant cultivation is an important component of the agricultural sector, combining economic feasibility with environmental significance and the pharmacological value of products.

The study established that climatic conditions play a decisive role in shaping both the yield and quality of medicinal raw materials. Temperature regimes, precipitation levels, light conditions, and air humidity directly influence plant physiological processes and the accumulation of biologically active compounds. At the same time, production efficiency largely depends on the ability to adapt agrotechnologies to specific natural and climatic conditions.

The comparative analysis demonstrated that Ukraine has significant natural potential due to fertile soils and diverse climatic zones. However, this potential is not fully realized due to insufficient technological support, limited access to investment, and weak integration with the processing industry. Poland demonstrates a more balanced development model, combining natural resources, state support, and modern technologies. Germany serves as an example of a highly efficient, innovative, and integrated model, where medicinal plant production is closely linked with the pharmaceutical industry.

An important finding of the study is the identification of a direct relationship between the level of technological development and the economic efficiency of production. The implementation of modern agrotechnologies, automation, and digital management systems allows for cost reduction, increased yields, and stable product quality. In this context, Ukraine significantly lags behind EU countries, which necessitates technological modernization of the sector.

The analysis of economic indicators showed that the efficiency of medicinal plant cultivation is determined by a combination of factors, including cost structure, production cost level, labor productivity, the degree of product processing, and market conditions. It has been established that increasing the level of processing is one of the key reserves for enhancing added value and profitability.

The study also confirmed the important role of organic production as a promising direction for sector development. Despite higher costs and certification complexity, organic medicinal plant cultivation ensures higher profitability due to strong demand and premium prices in international markets.

Special attention was paid to the role of state support, which in EU countries acts as a key factor in ensuring stable sector development. The system of subsidies, grants, and development programs promotes innovation, improves product quality, and strengthens the competitive position of producers. In Ukraine, however, insufficient and fragmented state support remains one of the limiting factors in sector development.

It has been established that risk management is an essential element of effective sector functioning. Climatic, market, technological, and financial risks can significantly affect production outcomes; therefore, their minimization is a necessary condition for sustainable development.

Particular importance is attached to the development of processing infrastructure, cooperation among producers, scientific support, and integration into international markets. These factors determine the possibility of transitioning from a raw-material model to the production of high value-added products.

Based on the conducted research, it is substantiated that the strategic directions for the development of medicinal plant cultivation in Ukraine should include:

- technological modernization of production;
- development of product processing;
- implementation of international quality standards;
- support for organic production;
- strengthening of state support;
- integration into the European market.

Overall, the research results confirm that medicinal plant cultivation has significant potential as a promising sector of agriculture, capable of ensuring economic growth, rural development, and strengthening the country's position in the international market.

In summary, it should be emphasized that improving the efficiency of medicinal plant cultivation in Ukraine is possible only through a comprehensive combination of natural potential, modern technologies, effective state policy, and integration into the global economic system. This will ensure sustainable sector growth and increased competitiveness.

REFERENCES

1. Bernáth J., (2018) Wild Growing and Cultivated Medicinal Plants. Budapest: Akademiai Kiado, 340 p.
2. Bundesministerium für Ernährung und Landwirtschaft, (2022) Medicinal Plants Production in Germany. Berlin, 65 p.
3. European Commission, (2020) Farm to Fork Strategy. Brussels, 20 p.
4. European Commission, (2020) The European Green Deal. Brussels, 24 p.
5. European Environment Agency, (2022) Climate Change and Agriculture in Europe. Copenhagen, 150 p.
6. European Medicines Agency, (2018) Guideline on Good Agricultural and Collection Practice (GACP) for Starting Materials of Herbal Origin. London, 25 p.
7. Eurostat, (2023) Agriculture, Forestry and Fishery Statistics. Luxembourg: Publications Office of the European Union, 220 p.
8. FAO, (2020) Good Agricultural Practices for Medicinal Plants. Rome, 95 p.
9. Food and Agriculture Organization of the United Nations, (2021) Medicinal and Aromatic Plants: Global Markets and Trends. Rome, 78 p.
10. Govindasamy R., (2020) Economics of medicinal plant production. Agricultural Economics Review, Vol.12, P.45–60.
11. International Trade Centre, (2021) Trade in Medicinal Plants. Geneva, 110 p.
12. Kintzios S., (2017) Medicinal and Aromatic Plants: Industrial Profiles. London: CRC Press, 512 p.
13. Lange D., (2019) The role of medicinal plants in Europe. Journal of Herbs, Spices & Medicinal Plants, Vol.25, P.1–15.
14. OECD, (2022) Agricultural Policy Monitoring and Evaluation 2022. Paris: OECD Publishing, 450 p.
15. OECD, (2021) Innovation, Productivity and Sustainability in Agriculture. Paris: OECD Publishing, 380 p.
16. Schippmann U., Leaman D., Cunningham A., (2018) Impact of cultivation and gathering of medicinal plants. Biodiversity and Conservation, Vol.27, P.123–135.
17. Statistics Poland, (2023) Agricultural Production Reports. Warsaw, 110 p.
18. World Health Organization, (2019) WHO Guidelines on Good Agricultural and Collection Practices (GACP) for Medicinal Plants. Geneva, 72 p.
19. Andriichuk V. H., (2018) Economics of Agricultural Enterprises. Kyiv: KNEU, 624 p.

20. Boiko I. O., (2018) Medicinal Plants: Cultivation and Use. Kyiv: Agrarian Science, 312 p.
21. Bondarenko V. M., (2017) Fundamentals of Crop Production. Kyiv: Urozhai, 384 p.
22. Verbytskyi P. I., (2019) Medicinal Plants and Their Application. Kyiv: Zdorovia, 290 p.
23. Havryliuk M. M., (2020) Agrotechnologies of Crop Cultivation. Kyiv: Agrarian Education, 310 p.
24. Hrodzinskyi A. M., (2019) Medicinal Plants of Ukraine. Kyiv: Urozhai, 384 p.
25. Derevianko O. P., (2021) Ecological Foundations of Crop Production. Kyiv: Lybid, 276 p.
26. State Statistics Service of Ukraine, (2023) Agriculture of Ukraine: Statistical Yearbook. Kyiv, 230 p.
27. Dudka I. O., (2020) Fundamentals of Pharmacognosy. Lviv: Svit, 256 p.
28. Zharkova I. O., (2022) Medicinal Plants in Modern Pharmacy. Kharkiv: Fakt, 298 p.
29. Zhuravel O. V., (2021) Technologies for Cultivation of Medicinal Plants. Kharkiv: Osnova, 298 p.
30. Zakharchuk O. V., (2019) Investment Support of Agricultural Production. Kyiv: NSC IAE, 265 p.
31. Ilchuk M. M., (2020) Organization of Agribusiness. Kyiv: NUBiP, 342 p.
32. Kalenska S. M., (2018) Crop Production with Basics of Agrotechnologies. Kyiv: NAU, 512 p.
33. Kyrychenko V. V., (2021) Breeding and Seed Production of Agricultural Crops. Kharkiv: Osnova, 355 p.
34. Kovalenko V. P., (2017) Agrotechnologies of Medicinal Crops. Kyiv: Center for Educational Literature, 276 p.
35. Kovaliv Yu. I., (2020) Organic Farming. Lviv: Svit, 290 p.
36. Kravchenko O. O., (2019) Management of Agricultural Production. Kyiv: Center for Educational Literature, 310 p.
37. Kucherenko M. Ye., (2022) Organic Production of Medicinal Plants. Kyiv: NSC IAE, 241 p.
38. Lavrynenko Yu. O., (2022) Modern Crop Production Technologies. Kyiv: Agrarian Science, 278 p.
39. Lisovyi M. P., (2019) Pharmacognosy with Basics of Plant Biochemistry. Kyiv: Medicine, 352 p.
40. Mazur V. A., (2021) Economics of Agriculture. Kyiv: KNEU, 420 p.
41. Melnyk S. I., (2018) Economics of Agricultural Production. Kyiv: KNEU, 410 p.
42. Mykhailov V. H., (2018) Efficiency of Agricultural Production. Kyiv: Urozhai, 300 p.
43. Ministry of Agrarian Policy and Food of Ukraine, (2022) Strategy for the Development of the Agricultural Sector of Ukraine. Kyiv, 95 p.
44. Nikitin O. V., (2020) Development of the Agricultural Sector of Ukraine. Kyiv: NSC IAE, 280 p.
45. Onyshchenko O. M., (2020) Economic Efficiency of Agricultural Production. Kyiv: Agrarian Education, 290 p.
46. Pavlenko I. S., (2021) Pharmacognosy of Medicinal Plants. Kyiv: Medicine, 360 p.
47. Patyka V. P., (2017) Biological Foundations of Crop Production. Kyiv: Urozhai, 368 p.
48. Petrychenko V. F., (2022) Modern Trends in Crop Production Development. Kyiv: Agrarian Science, 275 p.
49. Petriv M. V., (2019) Economics of Natural Resource Use. Lviv: Novyi Svit, 275 p.
50. Savchuk V. P., (2018) Economic Analysis of Enterprise Activity. Kyiv: KNEU, 420 p.
51. Sydorenko O. V., (2021) Medicinal Plants: Handbook. Kyiv: Naukova Dumka, 320 p.
52. Tarasenko O. I., (2021) Risk Management in the Agricultural Sector. Kyiv: Agrarian Education, 260 p.
53. Tkachenko N. M., (2019) Organization and Economics of Agribusiness. Kyiv: Center for Educational Literature, 305 p.
54. Fedorenko V. F., (2020) Innovative Technologies in Crop Production. Kyiv: Agrarian Science, 287 p.
55. Shevchenko O. V., (2021) Development of Organic Production in Ukraine. Kyiv: NUBiP, 210 p.

BIOLOGICAL AND ECOLOGICAL FEATURES OF THE FORMATION OF SEED PRODUCTIVITY OF LABURNUM ANAGYROIDES MEDIK. IN THE CONDITIONS OF THE LEFT-BANK FOREST-STEP OF UKRAINE

Sonora Yevhenii
Assistant, Sumy National Agricultural University, Ukraine
ORCID ID: 0009-0007-8116-2771

Tovstukha Oleksandr
Doctor of Philosophy, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0002-9925-3029

Introduction

Plant introduction is one of the leading approaches to enriching biodiversity and expanding the range of economically valuable, medicinal, and ornamental species. It plays an important role in the formation of stable and functionally complete phytocoenoses, contributing to increased ecological stability of urban and natural-anthropogenic landscapes. Introduction studies are aimed not only at incorporating new species into cultivation but also at assessing their adaptive potential, biological characteristics, reproductive capacity, and economic value under new environmental conditions.

Particular relevance is associated with the introduction of new tree and shrub species in temperate regions, where the assortment of ornamental introduced plants remains limited and is often represented by species with insufficient ecological plasticity. In this regard, there is a need to expand the species composition of plantings through the introduction of promising taxa capable of functioning effectively under changing climatic conditions. An important aspect is also the enhancement of biodiversity in urban ecosystems, which contributes to improving the microclimate, reducing air pollution levels, and increasing the aesthetic attractiveness of territories.

Under current climate change conditions, characterized by increasing aridity, more frequent extreme weather events, and rising temperature levels, special attention should be paid to the selection of species capable of combining high ornamental value, ecological plasticity, and resistance to abiotic stresses. Such stresses include moisture deficit, high temperatures, soil compaction, and increased anthropogenic pressure. In this context, the introduction of drought-tolerant and thermophilic species with a wide adaptive range is one of the key directions in modern ornamental horticulture and forestry.

A promising introduced species for landscaping and the establishment of plantings of various functional purposes is the golden chain tree (*Laburnum anagyroides* Medik., family Fabaceae). This species is widely used in ornamental horticulture across European countries due to its high aesthetic value, relative low maintenance requirements, and ability to form impressive compositions both in solitary and group plantings. The plant is characterized by outstanding декоративність, particularly during the flowering period, when long pendulous inflorescences with numerous yellow flowers create the distinctive visual effect known as the "golden rain" (Hartmann et al., 2010; POWO, 2021; FloraVeg/Euro+Med, 2025). This period is decisive in terms of the ornamental value of the species and determines its wide application in the landscaping of parks and gardens.

In addition to its декоративні properties, *Laburnum anagyroides* possesses a number of biological characteristics that enhance its value as an introduced species. As a member of the Fabaceae family, it is capable of forming symbiotic relationships with nitrogen-fixing bacteria, which contributes to the accumulation of biologically available nitrogen in the soil. This, in turn, positively affects soil fertility, increases its biological activity, and improves conditions for the growth of other plants within plant communities. This property is particularly valuable under conditions of degraded or low-fertility soils, where the introduction of leguminous species can perform a reclamation function.

At the same time, despite its considerable ornamental and ecological potential, the species requires comprehensive study under introduction conditions, particularly regarding its winter hardiness, drought tolerance, growth and development patterns, and reproductive biology. The assessment of these characteristics is a necessary prerequisite for substantiating the feasibility of its widespread use in landscaping and forestry practices.

The modern taxonomy of the species is characterized by a certain degree of synonymy, обусловлене its long history of description and refinement of its systematic position. In international botanical literature, *Laburnum anagyroides* is found under a number of synonymous names, including *L. anagyroides* subsp.

anagyroides, *L. platycarpum* Maire, *L. vulgare* J. Presl, *Cytisus laburnum* L., *C. alschingeri* (Vis.) C. Koch, as well as under the common English name "Golden Chain Tree" (Hartmann et al., 2010; Csurhes & Markula, 2016; POWO, 2021). Such diversity of nomenclatural variants requires unification in scientific research and practical applications to ensure accurate species identification and comparability of results.

In Ukrainian scientific and reference literature, the species is known under several common names, including *bobovnyk anahyrolystyi*, *bobovnyk zvychaynyi*, and occasionally "golden rain," the latter being directly associated with the characteristic morphology of its inflorescences and the abundant yellow flowering that creates a pronounced ornamental effect. This name is widely used in popular and landscape gardening practice; however, in scientific usage it has limited applicability due to its descriptive nature and lack of taxonomic specificity. At the same time, the term *bobovnyk* requires careful clarification in scientific contexts, as in some sources it may be applied to representatives of other genera within the Fabaceae family or even to species that do not belong to this family. In particular, it is sometimes erroneously used to refer to *Prunus tenella* L., which belongs to the Rosaceae family and is not taxonomically related to the genus *Laburnum* (Mamchur & Muskan, 2023; Pakhomov et al., 2023; Shlapak & Piskun, 2007). Such terminological ambiguity highlights the necessity of using Latin names in scientific research to ensure unambiguous and accurate species identification.

The etymology of the genus name *Laburnum* has ancient origins and is associated with the Etruscan linguistic tradition, where it referred to a "leguminous plant with trifoliate leaves." This reflects one of the characteristic morphological features of the genus – compound trifoliate leaves, typical of many legumes. The species epithet *anagyroides* is derived from the genus *Anagyris* and indicates the external similarity of the plant to the Mediterranean species *Anagyris foetida* L., which is also characterized by trifoliate leaves and yellow flowers. This similarity is primarily morphological and does not indicate close phylogenetic relatedness; rather, it reflects historical approaches to plant classification based on external traits.

The genus *Laburnum* was first described by P. C. Fabricius in 1759, and since then its systematic position has been repeatedly уточнювалося. According to modern taxonomic concepts, the genus comprises 3–4 species, among which the most well-known and widely distributed are *Laburnum anagyroides* Medik., *Laburnum alpinum* (Mill.) Bercht. & J. Presl, as well as their natural or artificially produced hybrid *Laburnum × watereri*. The latter occupies an intermediate position between the parental forms and is characterized by a combination of their ornamental and biological traits. In some taxonomic treatments, *Laburnum alschingeri* is also mentioned; some authors consider it a distinct species, while others treat it as a variation or form of related taxa. This reflects a certain degree of taxonomic ambiguity within the genus, обусловлену both morphological variability and the limited number of clearly defined diagnostic features.

In cultivation, numerous ornamental forms of *Laburnum anagyroides* have become widely распространені, differing in growth habit, crown shape, growth pattern, and leaf morphology. In particular, the form *f. pendula* is characterized by a weeping crown with pendulous branches, which enhances the ornamental effect during the flowering period. The form *f. aurea* is distinguished by its golden-colored foliage, which persists throughout the growing season and provides additional декоративність even outside the flowering phase. The form *f. quercifolia* has leaves resembling those of oak, which is a relatively rare feature among representatives of the Fabaceae family. A special place in ornamental horticulture is occupied by the hybrid *Laburnum × watereri* 'Sunspire', which combines abundant flowering with a more compact crown form and increased ornamental stability (Ferner, 1998). Owing to these characteristics, various forms and cultivars of golden chain tree are widely used in landscaping of urban and suburban areas.

Laburnum anagyroides is a deciduous woody plant of the Fabaceae family, naturally distributed mainly in Central and Southern Europe, particularly in mountainous and foothill regions, where it grows on well-drained, often calcareous soils. Under natural conditions, the species forms small trees or large shrubs 5–6 m in height, with a relatively narrow, sparsely branched crown and an upright or slightly curved trunk. The branches are typically thin and flexible, contributing to the characteristic openwork structure of the crown. Under favorable soil and climatic conditions, particularly with sufficient moisture and high soil fertility, plants may reach 9–10 m in height, with a crown diameter of 3–4 m (Shlapak & Piskun, 2007; Csurhes & Markula, 2016).

It should be noted that the morphometric parameters of the species may vary considerably depending on growing conditions, indicating its relative ecological plasticity. In cultivation, especially under urban conditions, plants often exhibit smaller dimensions due to limited soil volume, substrate compaction, and the influence of anthropogenic factors. Nevertheless, *Laburnum anagyroides* maintains a high level of ornamental value, making it a valuable component of modern green spaces.

In young plants, the crown is irregular, relatively narrow, and often asymmetric, which is обусловлено the intensive growth of apical shoots and the still insufficiently developed system of lateral branching. At this stage, it exhibits a somewhat open structure, with a predominance of vertically oriented branches. With age, the crown gradually expands, becomes denser, and acquires a more regular ovate or broadly ovate shape. In mature specimens, a more balanced architectural structure is formed; however, the crown generally retains a certain openness, which contributes to its ornamental appeal and its ability to transmit light.

The main shoots are upright, strong, light brown to brownish-grey in color, with a smooth or slightly fissured surface. Young branches are greenish-grey and covered with a characteristic silvery pubescence, which performs a protective function by reducing transpiration and protecting tissues from overheating. With age, the shoots become lignified, acquire a grey-brown coloration, and often become pendulous, which is one of the characteristic morphological features of the species and further enhances its decorative effect, particularly during the flowering period. The bark on older branches may become slightly fissured, forming longitudinal cracks.

The buds are arranged alternately, broadly ovate in shape, relatively small, and closely appressed to the shoots. They are covered with several light brown or brown scales that perform a protective function, safeguarding the primordial organs from unfavorable winter conditions. Generative buds are usually larger than vegetative ones and are formed on shortened shoots of the previous year.

The leaves are alternate, compound, trifoliate, with entire margins and a cuneate or slightly narrowed base. Each leaf consists of three leaflets, of which the central one is typically larger and borne on a longer petiolule. The leaf blade is elongated-elliptical or obovate, with a blunt or slightly pointed apex. The average leaf length is 7–8 cm and width 2.5–3.0 cm; however, these parameters may vary depending on growing conditions and plant age.

The petioles are 2–7 cm long, well developed, and covered with silvery-white pubescence, which is particularly pronounced on young organs. Young leaves are greyish-green in color and have a velvety surface due to dense pubescence composed of fine trichomes. This indumentum plays an important role in regulating the plant’s water balance by reducing transpiration and protecting tissues from excessive solar radiation. During the period of full vegetation, the adaxial surface of the leaf blade becomes dark green, smooth, and glossy, whereas the abaxial surface remains lighter and often retains slight pubescence. Such differentiation of leaf surfaces contributes to efficient photosynthesis and regulation of gas exchange.

The flowers are bisexual, zygomorphic, and of the papilionaceous type, which is typical of representatives of the Fabaceae family. They consist of five free petals differentiated into a standard (banner), wings, and keel. The perianth is bright yellow, sometimes with brownish or reddish streaks that function as nectar guides for pollinators. The standard petal is significantly larger than the others, broadly ovate, with a characteristic notch at the apex, measuring 18–22 mm in length. The wings are elongated and partially enclose the keel, which is formed by two fused petals and protects the stamens and pistil.

The calyx is campanulate, approximately 5 mm long, with five unevenly developed teeth. Both the calyx and the pedicels (8–12 mm long) are covered with silvery pubescence, which is a characteristic feature of the species. The androecium consists of ten stamens, nine of which are fused into a tube while one remains free, corresponding to the diadelphous type. The gynoecium is represented by a single pistil with a superior ovary.

The flowers are arranged in multi-flowered pendulous inflorescences–racemes–measuring 20–30 cm in length, and under favorable conditions may reach even greater sizes. A considerable number of flowers can be formed within a single inflorescence, ensuring abundant and prolonged flowering. The pendulous nature of the inflorescences, combined with their substantial length, creates the characteristic ornamental effect that has given rise to the common name “golden rain.” Flowering typically occurs in the spring–early summer period and is accompanied by high nectar production, which promotes active attraction of insect pollinators (Ferner, 1998; Stawiarz & Wróblewska, 2013).

In general, the morphological features of the aboveground organs of *Laburnum anagyroides* indicate its adaptation to conditions of sufficient light and moderate moisture, and also determine its high ornamental value, which is an important factor in its widespread use in landscaping.

The fruit is a dry, dehiscent, flattened, multi-seeded legume of linear-oblong shape, 2–8 cm long and approximately 0.5–1.5 cm wide. At early stages of development, the fruits are green and densely pubescent, with the indumentum gradually diminishing with age. At maturity, they acquire a light brown or brown coloration, become smooth, and sometimes slightly glossy. The surface of the pod may exhibit faint longitudinal veins. The fruit walls are relatively thin but sufficiently strong, ensuring seed preservation for an extended period after maturation.

The pods are generally straight or slightly curved, sometimes slightly constricted at the positions of the seeds. Fruit dehiscence occurs along two sutures; however, this process is not always complete, which results in partial seed retention within the pods during the winter period. Each pod contains from 1 to 9 seeds, dark brown to almost black in color, rounded or slightly reniform in shape, measuring 2–4 mm (Szentesi, 2006; Csurhes & Markula, 2016). The seeds are characterized by a dense, water-impermeable coat, which determines their state of physiological dormancy and necessitates pre-treatment (scarification) to improve germination.

An important biological feature of the fruits of *Laburnum anagyroides* is the presence of alkaloids, particularly cytisine, which confers toxicity to humans and animals. This is significant both from the perspective of safe use of the species in landscaping and in terms of natural protection of seeds against herbivory.

The vegetation of *Laburnum anagyroides* in its natural range begins in April, corresponding to the establishment of stable positive temperatures and the activation of physiological processes in the plant. In more northern regions, including the Forest-Steppe zone of Ukraine, the onset of vegetation shifts to later dates – usually to late April or early May – due to climatic conditions and a longer period of spring cooling. Bud break occurs relatively synchronously, ensuring coordinated development of the leaf apparatus.

Annual shoot growth is characterized as moderate and averages 2–4 cm; however, in young plants or under favorable growing conditions, this value may be higher. Growth intensity largely depends on moisture availability, soil fertility, and light conditions. Under limited moisture supply or in compacted soils, shoot growth may decrease significantly, reflecting the species' sensitivity to edaphic and hydrological conditions.

Flowering under natural conditions begins in the second decade of May and lasts on average 17–28 days. This period is characterized by high intensity of flower opening and pronounced ornamental expression. Under introduction conditions, the timing of flowering may vary depending on regional climatic factors, particularly the temperature regime in spring. In Central and Eastern Europe, including Ukraine, flowering typically occurs from May to early June and lasts 15–20 days. Under unfavorable weather conditions, such as late spring frosts, prolonged cool or rainy weather, disturbances in bud formation, irregular flowering, or even its complete absence in certain years may occur (Stawiarz & Wróblewska, 2013; Poçta & Florin, 2017). This is an important factor to consider when assessing the ornamental stability of the species.

Fruit maturation within the natural range occurs at the end of August, whereas under introduction conditions this process is usually shifted to September. The duration of fruit formation and maturation depends on the weather conditions of the growing season, particularly temperature and precipitation. Some pods dehisce already in autumn, ensuring natural seed dispersal; however, a considerable proportion remains on the plants until spring. This feature promotes gradual seed release and may be regarded as an adaptive mechanism that increases the likelihood of successful germination under varying environmental conditions.

The completion of the growing season largely depends on the temperature regime of the autumn period. Under conditions of an early decrease in temperature, leaf fall occurs rapidly and is often accompanied by the partial abscission of immature leaves. In contrast, during a prolonged warm autumn, vegetation may continue until the end of October or even the beginning of November. Under the conditions of the Forest-Steppe zone of Ukraine, the completion of vegetation typically occurs in mid to the second half of October, which is consistent with the general phenological patterns of development of woody introduced species in this region.Overall, the phenological characteristics of *Laburnum anagyroides* indicate its good adaptation to temperate climatic conditions; however, at the same time, they demonstrate a certain dependence on weather factors, which should be taken into account in the introduction assessment of the species as well as in planning its use in landscaping.

The natural range of *Laburnum anagyroides* encompasses the southern parts of Central Europe and Southeastern Europe, where the species occurs within the temperate biome with elements of sub-Mediterranean climatic influence (POWO, 2021). The main centers of its distribution are concentrated in mountainous and foothill regions, particularly in the Alps, the Carpathians, and the Balkan Peninsula, where it forms part of open deciduous forests, forest edges, shrub thickets, and petrophytic communities. Generalized floristic syntheses for Europe confirm the presence of the species in regional floras and indicate its affinity for warmer and relatively drier habitats compared to *Laburnum alpinum*, as well as its more frequent association with alkaline (calcareous) substrates (Trees and Shrubs Online, 2024; FloraVeg/Euro+Med, 2025).

Under natural conditions, *Laburnum anagyroides* predominantly grows on rocky slopes, screes, and in fissures and niches of limestone outcrops, where well-drained, shallow, and often skeletal soils with a high carbonate content and significant aeration are formed. Such ecotopes are characterized by limited water-holding capacity, pronounced temperature fluctuations, and a high level of solar radiation, which create specific conditions for the development of adaptive plant traits. These habitats correspond to the European typology of calciphilous rocky environments (limestone cliffs and chasmophytic communities), which are characterized by a deficit of soil moisture, shallow soil profiles, and low competition from other species (EUNIS, 2025). Under such conditions, *Laburnum anagyroides* acts as a competitive species due to the combination of drought tolerance, a light-demanding nature, and the ability to efficiently utilize limited resources.

Data on ecological and functional traits of the species in European plant trait databases further emphasize its adaptation to well-drained substrates, high insolation, and seasonally dry conditions (FloraVeg/Euro+Med, 2025). In particular, the presence of pubescence on young organs, relatively small leaf size, and their specific morphological structure contribute to a reduction in transpiration and an increase in water-use efficiency. In addition, the ability to form symbiotic associations with nitrogen-fixing bacteria provides an additional advantage under nutrient-poor soil conditions, where the availability of accessible nitrogen is limited.

In terms of ecological preferences, *Laburnum anagyroides* belongs to light-demanding species of the temperate zone, which most effectively realize their decorative and generative potential under conditions of full insolation. In open habitats, plants form a more compact, well-foliated crown and are characterized by intensive flowering and stable fruiting. Under the canopy or in partial shade conditions, plants are able to maintain viability; however, their growth becomes more elongated, the crown more sparse, and the intensity of flowering as well as the level of fruiting are significantly reduced, which is typical of light-demanding woody introduced species (FloraVeg/Euro+Med, 2025).

An important characteristic of the ecological amplitude of a species is its response to moisture conditions. *Laburnum anagyroides* exhibits xeromesophytic traits, that is, the ability to withstand periods of moderate drought provided that the soil is well-drained. Excessive moisture, especially in combination with heavy clay soils, negatively affects plant growth and development, causing suppression of the root system. This necessitates careful consideration of hydrological conditions when introducing the species.

The assessment of environmental gradients based on Ellenberg indicator values (light, moisture, soil reaction, nitrogen availability, etc.) is a widely accepted approach for interpreting plant ecological requirements and comparing species across different regions (Hill et al., 2000; FloraVeg/Euro+Med, 2025). The application of this approach makes it possible to quantitatively characterize the ecological niche of a species and to evaluate its acclimatization potential. For *Laburnum anagyroides*, typical indicator values include high light demand, preference for neutral to slightly alkaline soils, and moderate moisture conditions, which is consistent with its natural association with open calciphilous habitats.

The use of Ellenberg indicator values is also appropriate for introduction studies of *Laburnum anagyroides* in the Forest-Steppe zone of Ukraine, as it allows the formalization of the influence of key ecological factors – light, moisture, and soil reaction – on plant growth, development, and reproductive capacity. Such an approach contributes to substantiating optimal cultivation conditions, improving the efficiency of its use in landscaping, and predicting its performance under future climate change scenarios.

In general, the ecological characteristics of *Laburnum anagyroides* indicate that it belongs to a group of species with a relatively wide ecological amplitude, but with a clearly expressed preference for well-lit, well-drained, and calcareous habitats, which is of key importance when assessing its introduction potential.

The soil requirements of the species are associated with its natural affinity for calcareous substrates, which determines its preference for neutral or slightly alkaline soils with sufficient calcium content. The most favorable conditions for the growth and development of *Laburnum anagyroides* are light to medium loamy soils with good water and air permeability, as well as effective drainage that prevents moisture stagnation in the root zone. At the same time, the species is capable of growing on relatively poor and shallow soils, which indicates its adaptation to conditions of limited mineral nutrition.

The negative response of *Laburnum anagyroides* to excessive moisture, waterlogging, and soil compaction is primarily related to the functional characteristics of its root system, which requires a high level of aeration. Excessive moisture conditions lead to root hypoxia, resulting in the suppression of growth processes, reduced intensity of mineral nutrition, and, consequently, general weakening of the plants. Soil compaction, which is typical of urban environments, further restricts the penetration of air and water to the roots, thereby negatively affecting plant vitality and ornamental value (Trees and Shrubs Online, 2024; FloraVeg/Euro+Med, 2025).

From a practical perspective, this implies that under the conditions of the Forest-Steppe zone of Ukraine, proper site selection for planting is of critical importance. Preference should be given to well-drained sites, while low-lying areas prone to water stagnation should be avoided. In addition, irrigation intensity should be carefully regulated, especially on heavy soils. An important agrotechnical measure is also the prevention of soil compaction in the tree pit area, which can be achieved through mulching, limiting recreational pressure, and the use of soil-structuring materials.

Climatically, *Laburnum anagyroides* is associated with the temperate zone and is characterized by sufficient winter hardiness, allowing it to withstand seasonal decreases in temperature. However, the degree of resistance largely depends on the age of the plants and the nature of weather conditions during the winter period. The most vulnerable are young shoots, which may be damaged by prolonged extreme frosts or abrupt temperature fluctuations, especially in the absence of snow cover (Poçta & Florin, 2017). An additional negative factor is early spring thaws, which stimulate premature activation of growth processes, after which subsequent frosts may damage both generative and vegetative organs.

For the introduction assessment of the species, it is particularly important to consider the sensitivity of the generative sphere to abiotic stresses. The processes of flower bud formation, pollination, fruit set, and seed maturation represent the most vulnerable phases of ontogenesis and largely determine the reproductive success of the species. Late spring frosts may damage buds and flowers, leading to a reduction or complete loss of seed yield. Summer droughts limit water availability to plants, negatively affecting fruit development, whereas excessive soil moisture may cause ovary abscission and promote the development of pathogens (Poșta, 2018; FloraVeg/Euro+Med, 2025). Thus, the generative potential of *Laburnum anagyroides* serves as an integral indicator of its adaptation to specific environmental conditions.

Historically, *Laburnum anagyroides* has been widely cultivated as an ornamental woody plant far beyond its natural range, due to its high aesthetic value and relative ecological tolerance. In a number of regions worldwide, studies have been conducted to assess its capacity for naturalization, as well as to evaluate potential risks of invasiveness. Although in most cases the species does not exhibit aggressive invasive behavior, the existence of such studies indirectly indicates its ecological plasticity and its ability to adapt to new environments under favorable conditions (Csurhes & Markula, 2016).

An important direction in modern landscaping is the use of plants with phytoremediation potential, that is, species capable of improving the ecological condition of urbanized areas by reducing anthropogenic pressure, accumulating pollutants, and stabilizing the soil environment. In this context, increasing attention is being paid to ornamental species that combine high adaptability with the ability to function under conditions of air pollution, soil compaction, moisture deficiency, and other stress factors typical of urban environments.

Laburnum anagyroides is characterized by a sufficient level of tolerance to such conditions, including resistance to atmospheric pollution, temperature fluctuations, and periodic water deficit. This provides a basis for considering it as a promising component of urban green spaces, particularly in street plantings, parks, and recreational areas. An additional advantage of the species is its ability to form symbiotic associations with nitrogen-fixing bacteria of the genus *Bradyrhizobium*, which is accompanied by the formation of root nodules and ensures the biological fixation of atmospheric nitrogen (Sajnaga, Jach, 2020; Łotocka, 2024).

Biological nitrogen fixation in the “legume – rhizobia” system is considered one of the key mechanisms for increasing soil fertility, especially under conditions of soil degradation or anthropogenic disturbance. As a result, the content of available nitrogen forms increases, microbiological activity is enhanced, and the physicochemical properties of the soil are improved (Stępkowski et al., 2018; Jach et al., 2022). Thus, the use of *Laburnum anagyroides* in plantings may have not only decorative but also significant ecological importance.

The combination of high ornamental value, ecological plasticity, relative resistance to abiotic factors, and the ability for biological nitrogen fixation determines the feasibility of further comprehensive studies of this species. Of particular relevance are investigations of its reproductive biology, seed productivity, seed germination characteristics, and adaptive potential under urban conditions, which are essential for substantiating the effective use of *Laburnum anagyroides* in modern landscaping and phytomelioration.

Despite its considerable ornamental, ecological, and phytomeliorative potential, *Laburnum anagyroides* is still used to a limited extent in landscaping in Ukraine, particularly in the Left-Bank Forest-Steppe zone. Within the structure of urban and suburban plantings, the species is represented by individual specimens or small groups, which does not allow for the full realization of its aesthetic and ecological advantages. This situation is обусловлена a number of factors, among which insufficient knowledge of the species’ biological characteristics under introduction conditions, a limited availability of adapted planting material, and the lack of established technologies for its mass propagation are of primary importance.

One of the main reasons for the limited introduction of *Laburnum anagyroides* into landscaping practice is the difficulty of its propagation, particularly by seeds. This is associated with a number of biological features of the seeds, including the presence of a dense water-impermeable seed coat, which determines physiological (and partly physical) dormancy, as well as the uneven maturation of fruits and seeds within a single plant. An additional complicating factor is the variability of germination rates, which largely depends on the conditions of seed formation, the degree of maturity, and post-harvest processing.

In the natural range, these features are compensated by a prolonged period of natural stratification and gradual seed germination, which ensures species survival under variable environmental conditions. However, under introduction conditions, particularly in the Left-Bank Forest-Steppe of Ukraine, such mechanisms are not always effective, which is manifested in low field germination, an extended germination period, and uneven seedling emergence. This, in turn, complicates the production of standard planting material and reduces the efficiency of the species' use in landscaping.

An important aspect is also the influence of environmental conditions on seed formation. Temperature regime, moisture availability, pollination conditions, and the overall physiological state of mother plants may significantly affect seed morphological characteristics, mass, viability, and germination capacity. In this regard, the study of seed productivity under specific soil and climatic conditions becomes particularly important, as it allows the assessment of the adaptive potential of the species and the determination of optimal conditions for its propagation.

In the context of modern introduction studies, a comprehensive approach to the investigation of seed productivity is of particular importance. This includes the analysis of quantitative indicators (seed yield, number of seeds per fruit, weight of 1000 seeds) and qualitative indicators (germination energy, laboratory and field germination, viability). Special attention should also be paid to the study of pre-sowing seed treatments (scarification, stratification, combined methods), which can significantly increase germination rates and synchronize the germination process.

In this regard, a comprehensive study of the seed productivity of *Laburnum anagyroides* under the conditions of Sumy region is highly relevant. Such a study involves the assessment of quantitative and qualitative seed characteristics, investigation of the peculiarities of seed formation, maturation, and germination, as well as the identification of the main factors limiting the effectiveness of seed propagation of the species under introduction conditions. The obtained results may serve as a scientific basis for the development of effective methods for producing planting material and for expanding the use of the species in landscaping.

The aim of the study is to investigate the features of seed productivity of *Laburnum anagyroides* and to assess the prospects for its propagation under the conditions of the Left-Bank Forest-Steppe of Ukraine (Sumy region).

To achieve this aim, the following main objectives were formulated:

to study the peculiarities of flowering and fruiting of the species under introduction conditions;

to determine indicators of seed productivity (number of fruits, number of seeds, seed mass);

to assess seed quality based on germination and viability parameters;

to establish the effect of pre-sowing treatments on seed germination;

to identify the main ecological and biological factors limiting seed propagation of the species.

In general, the results of such studies have not only theoretical but also practical significance, as they contribute to the improvement of technologies for cultivating ornamental introduced species and to the expansion of the assortment of plants suitable for use in modern urban environments.

Material and Methods

The study was conducted in 2024 using seed material of *Laburnum anagyroides* collected from donor plants aged 12–15 years, which were in the generative phase of development. The experimental plants were grown under field conditions in the dendrarium of Sumy National Agrarian University (geographical coordinates: 50.9076° N, 34.7981° E), located within the Left-Bank Forest-Steppe zone of Ukraine. The climatic conditions of the region are characterized by a moderately continental climate, with relatively warm summers and moderately cold winters, which creates representative conditions for assessing the introduction potential of the species.

Seed collection was carried out in late September to early October, after the completion of the growing season and upon reaching full fruit maturity. The selection criteria included the characteristic coloration of the pods (light brown), their partial drying, and the onset of natural dehiscence. This approach ensured the collection of morphologically mature and physiologically полноценного seed material with maximum viability indicators. In the experiment, freshly collected, well-filled seeds were used (Fig. 1), which made it possible to minimize the influence of post-harvest storage factors on the experimental results.

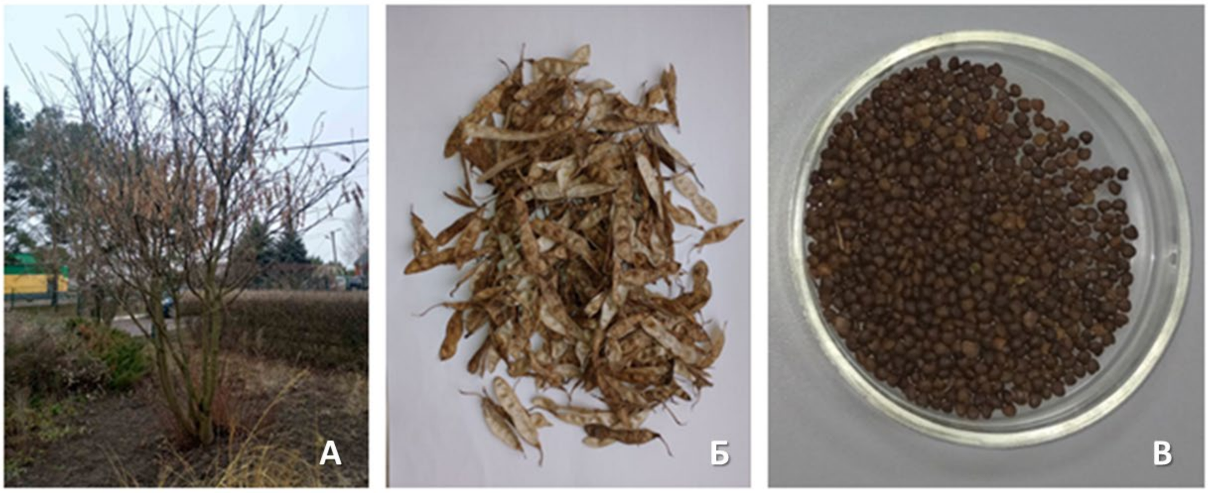


Figure 1. Donor plant (A), fruits (B), and seeds (C) of L. anagyroides

After collection, the fruits were subjected to primary processing, which included drying under natural ventilation at room temperature in order to facilitate seed extraction. Seed extraction was performed manually by opening the pods, followed by separation of fully developed seeds from underdeveloped, damaged, or infected ones. The cleaned seeds were additionally dried to an air-dry state, which ensured the stability of their mass and their suitability for further measurements.

The weight of 1000 seeds was determined in accordance with generally accepted seed science methodologies, taking into account the requirements of international standards. Weighing was carried out using Certus Balance analytical scales with a measurement accuracy of ±0.01 g. To increase the accuracy of the results, two subsamples of 500 seeds each were taken, after which the obtained values were recalculated per 1000 seeds. This approach complies with the requirements of the *International Rules for Seed Testing* (ISTA, 2004) and allows for obtaining representative data on seed mass as one of the key indicators of seed quality.

The number of seeds per fruit was determined by manual counting using a series of representative samples. For this purpose, the pods were preliminarily sorted according to the number of developed seeds into one-, two-, three-, four-, and five-seeded groups, which made it possible to assess the structure of seed productivity of the species. Taking into account the variability of this parameter is important for characterizing the reproductive potential of plants and for evaluating the efficiency of pollination and fertilization.

To determine the average number of seeds per fruit, four replicates were used, each consisting of 10 g of fruit mass. This approach ensured a sufficient sample size to obtain statistically reliable results. During the analysis, both the total number of seeds and their distribution among fruit categories were taken into account.

The obtained data were recorded in data sheets and subsequently processed using methods of variation statistics. Mean values, variability, and errors were calculated, which made it possible to assess the degree of variation of the studied traits and to ensure the reliability of the obtained results. Statistical data processing is an essential component of studies of this type, as it allows for objective interpretation of the results and the identification of patterns in the formation of seed productivity.

In general, the applied research methodology provides a comprehensive assessment of both quantitative and qualitative characteristics of *Laburnum anagyroides* seeds and creates a reliable basis for further analysis of their sowing qualities and germination characteristics under introduction conditions.

Seed mass was determined based on the average weight of 1000 seeds and the actual number of seeds in each pod, which made it possible to assess the overall seed yield potential of the plants and the structure of productivity distribution among individual fruits. For this purpose, each pod was weighed using an analytical balance, after which the seed mass was calculated using a formula that took into account the number of seeds per fruit and the mean weight of one thousand seeds.

The proportion of waste was determined as the percentage of plant material that did not contain fully developed or morphologically formed seeds, as well as mechanical impurities and plant debris. The analysis of waste made it possible to evaluate the efficiency of seed collection and its quality, which is important for planning sowing technologies and the production of planting material.

Climatic conditions during the growing season were considered as one of the factors influencing the formation of generative organs and seed productivity. For this purpose, data from the Sumy Regional Meteorological Station were used, including mean monthly air temperature and total precipitation during the 2024 growing season. The conducted analysis made it possible to assess the influence of weather conditions on flowering time, fruiting intensity, and seed quality, which is particularly important for species with limited introduction adaptability.

Statistical analysis of the obtained results was performed using the software package Statistica 9.0. Methods of variation statistics were applied to determine mean values, standard deviations, coefficients of variation, and correlation analysis between different indicators of seed productivity. The results were summarized using analytical methods with further interpretation in the context of the ecological conditions of the study region. This approach made it possible to identify patterns in the formation of the seed potential of *Laburnum anagyroides* and to assess the influence of environmental factors on both quantitative and qualitative seed characteristics.

The application of a comprehensive approach to the collection, processing, and analysis of seed material ensured the scientific validity of the conclusions regarding the introduction potential of the species and its practical value in landscaping within the Left-Bank Forest-Steppe of Ukraine.

Results

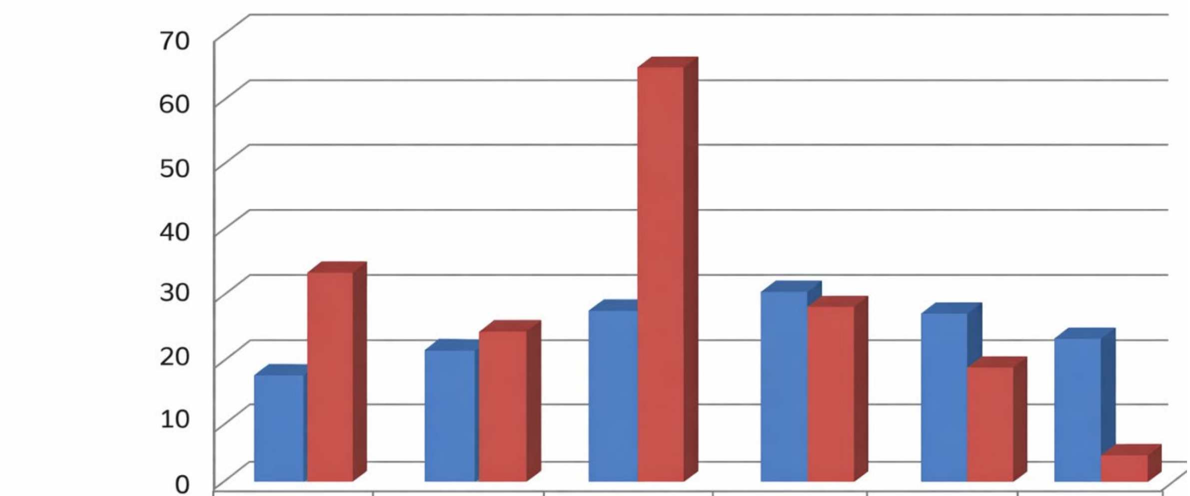
During the 2024 growing season, climatic conditions in the study area were generally characterized by a favorable temperature regime; however, moisture availability was uneven, which significantly affected the course of plant growth and reproductive processes. The average monthly temperatures from April to September remained within ranges close to optimal for the growth and development of *L. anagyroides*, ensuring the active progression of the main phenological stages. A gradual increase in temperature from spring values to the summer maximum was observed, corresponding to the general pattern of seasonal climate dynamics in the region. The highest temperatures were recorded in July, when plants were in the phase of intensive growth and formation of generative organs, a critically important stage for the establishment of future seed productivity.

At the same time, analysis of the moisture regime indicates a significant unevenness in the distribution of atmospheric precipitation during the growing season. The maximum amount of precipitation occurred in June, which had a positive effect on vegetative growth, leaf area formation, and the overall physiological condition of the plants. However, subsequently, particularly in August and especially in September, a sharp decrease in precipitation was observed, leading to the development of soil and atmospheric drought conditions. Such a shift in the hydrothermal regime is крайне unfavorable, as the second half of summer represents a critical period for seed formation, filling, and maturation. It is during this time that intensive accumulation of assimilates, their translocation to generative organs, and the completion of seed morphogenesis take place.

Moisture deficiency during this period leads to disturbances in plant water balance, reduced photosynthetic intensity, and a slowdown in biosynthetic processes, which in turn negatively affects the formation of fully developed seeds. Limited soil moisture may have resulted in partial reduction of ovules, decreased seed filling, and the formation of seeds with lower individual weight. This is also accompanied by an increased proportion of shriveled or underdeveloped seeds in the yield (Fig. 2).

The obtained experimental data confirm the identified patterns and are consistent with the weather conditions of the study year. A relatively low thousand-seed weight was recorded, along with the predominance of pods containing a limited number of fully developed seeds. Such indicators are a typical response of leguminous crops to water stress during the seed filling and maturation stages, as repeatedly reported in scientific studies. At the same time, the temperature regime throughout the growing season remained within the ecological optimum of the species, indicating the absence of significant thermal limitation of physiological processes.

Thus, the conducted analysis provides grounds to conclude that the deficit of atmospheric precipitation and the associated water stress in the second half of the growing season were the determining factors limiting the realization of the potential seed productivity of *L. anagyroides* in 2024. The temperature factor played a secondary role and did not exert a critical influence on seed yield formation.



	April	May	June	July	August	September
Average temperature (°C)	12,9	15	21,7	24,9	22,3	19,6
Precipitation (mm)	32	18	63	22	14	2

Figure 2. Average monthly air temperature and precipitation (Sumy, April–September 2024)

The Selyaninov hydrothermal coefficient (HTC) during the 2024 growing season (April–September) was 0.42, which, according to the generally accepted interpretation scale, characterizes the year as dry. HTC values below 0.5 indicate a significant moisture deficit and the development of water stress conditions for plants, especially during periods of active growth and generative development.

A more detailed analysis of the indicator dynamics across individual overlapping periods of the growing season reveals a clear trend toward deterioration of moisture conditions. In particular, during April–June, the HTC value was 0.75, corresponding to a relatively satisfactory level of moisture supply and promoting active growth of vegetative organs. Subsequently, a gradual decline in the indicator was observed: to 0.55 in May–July and to 0.47 in June–August, indicating a transition to moderately dry conditions. The most critical period was July–September, when the HTC decreased to 0.19, characterizing very dry conditions and indicating a severe deficit of available soil moisture.

It should be emphasized that this period coincides with the stages of seed filling and maturation, which are the most sensitive to water regime. Under such conditions, the transport of assimilates to generative organs is significantly disrupted, the intensity of photosynthetic activity decreases, and the synthesis of storage compounds slows down. As a result, this leads to the formation of insufficiently filled seeds, a reduction in their weight, and an increased proportion of shriveled or morphologically underdeveloped seed material.

Thus, the climatic conditions of the study year were generally suitable for plant growth and development, as confirmed by the absence of critical temperature deviations during the growing season. At the same time, the uneven moisture regime, with a pronounced precipitation deficit in the second half of the growing season, acted as a limiting factor in the formation of generative productivity. This highlights the necessity of considering the water factor as one of the key ecological determinants when assessing the reproductive capacity of introduced woody species, as well as when predicting their seed productivity under conditions of climate change.

According to laboratory studies, the average thousand-seed weight of *L. anagyroides* was 8.54 g. This value can be assessed as relatively low, indicating insufficient seed filling. This result is consistent with the identified unfavorable hydrothermal conditions of the second half of the growing season, particularly the critically low HTC values during the seed filling and maturation stages. Limited water supply during this period likely led to a decrease in the accumulation of storage substances in the seeds and their incomplete development.

At the same time, the variation in thousand-seed weight between replicates was insignificant, indicating relative uniformity of the studied material and stability of this trait within the sample. This allows the obtained results to be considered representative and adequately reflecting the influence of the environmental conditions of the year on the formation of seed productivity in the species.

To assess the degree of realization of reproductive potential, an analysis of seed set within fruits was conducted, which serves as an important indicator of the efficiency of generative processes – from flowering and pollination to seed formation and maturation. The obtained results indicate a pronounced unevenness in seed filling of pods and a limited realization of potential fertility.

In particular, it was established that the majority of fruits were single-seeded (75 units) and two-seeded (56 units), which together constitute the dominant group of fruits with low seed productivity. The number of three- and four-seeded pods was significantly lower, amounting to 26 and 10 units, respectively, while the proportion of five-seeded fruits was minimal – only 2 units. Such a distribution demonstrates a clear tendency toward a decrease in the number of fruits with higher seed set and indicates incomplete realization of the potential number of ovules within a single fruit.

The conducted analysis of variance (ANOVA) did not reveal statistically significant differences among the studied samples, as the variation of the indicators remained within the critical values according to Duncan's test at a significance level of $p \leq 0.05$ for each group (Table 1). This allows us to conclude that the studied material is relatively homogeneous and that the trait is stably expressed within the variation series.

Table 1. Quantitative characteristics of fruit seed set in *L. anagyroides*

Sample number	Number of beans pcs.				
	single-seeded	two-seeded	three-seeded	four-seeded	five-seeded
1	87	63	24	3	2
2	66	49	37	11	2
3	62	61	26	8	2
4	84	52	17	16	2
Average	75	56	26	10	2
Duncan test $_{0.05}$	*17,3*	*8,8*	*12,1*	*7,9*	*0,3*

On average, 169 fruits were recorded per sample, containing a total of 313 seeds, which made it possible to determine the mean number of seeds per pod at the level of 1.85. This value is relatively low and further confirms the limited seed productivity under the studied conditions. From a biological perspective, this may result from both incomplete fertilization and the subsequent reduction of a portion of ovules during their development.

For a more detailed analysis of the nature of the observed pattern, the proportion of fruits with different numbers of seeds was determined (Fig. 3). Structural analysis revealed the predominance of fruits with a minimal number of seeds and an extremely low proportion of multi-seeded forms. In particular, the share of fruits with high seed set is negligible, indicating a limited realization of the potential fertility of generative organs.

It should be noted that the sufficient level of moisture in June, which coincided with the period of mass flowering, would theoretically have favored effective pollination and the formation of a greater number of fully developed ovaries. Under such conditions, a higher proportion of multi-seeded fruits could have been expected. However, under the conditions of 2024, this potential was not realized: the proportion of such fruits amounted to only 1.2%. This indicates that the favorable conditions at the initial stages of generative development were offset by the subsequent moisture deficit in the second half of the growing season.

Water stress during the seed filling and maturation stages likely intensified competition among ovules for assimilates, resulting in their partial reduction and the formation of fruits containing fewer fully developed seeds. Thus, the established structure of fruit seed set reflects the combined influence of environmental factors, among which moisture deficit played the decisive role in 2024.

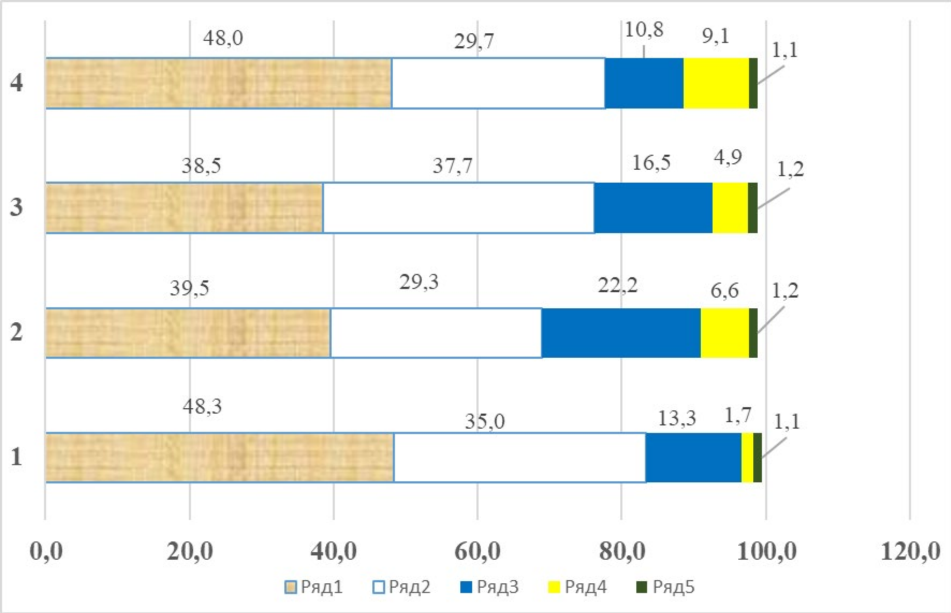


Figure 3. Proportion of L. anagyroides pods with different number of seeds, %

At the same time, moisture deficiency during the seed filling period led to an increased level of flower abortion and the predominance of one- and two-seeded pods, whose proportions were the highest, amounting to 43.6% and 32.9%, respectively. Such values indicate only partial realization of the generative development potential and are characteristic of the species under conditions of introduction, particularly under moisture deficit.

Based on the ratio between seed mass and total pod mass, it was determined that from 10 g of initial material, an average of 2.69 g of fully developed seeds was obtained. In terms of 1 kg, this corresponds to approximately 269 g, meaning that the proportion of viable seeds was about 27%. The remaining mass consisted of pod shells and underdeveloped or empty seeds.

The obtained results indicate that in 2024 the seed productivity of *L. anagyroides* was moderate. Despite the formation of a considerable number of fruits, the realization of reproductive potential was limited by unfavorable hydrothermal conditions, primarily moisture deficit during the seed filling and maturation stages. This resulted in reduced seed weight and a high proportion of low-seeded fruits.

Thus, the results of the study confirm the significant dependence of seed productivity in *L. anagyroides* on annual weather conditions and highlight the importance of considering the hydrothermal regime when assessing the prospects of seed reproduction of the species under the conditions of the Sumy region.

Conclusions

The seed productivity of *L. anagyroides* is shaped by a complex of biological and environmental factors, among which weather conditions during the growing season play a leading role, particularly the moisture regime during the seed filling and maturation stages. The results obtained in this study indicate that in 2024 the realization of the species' generative potential occurred under conditions that were not optimal for полноценне seed formation.

Analysis of climatic data for the period April–September 2024 showed that the total precipitation amounted to 151 mm, with an अत्यчно uneven distribution. The highest precipitation occurred in June, whereas in August and especially in September a sharp moisture deficit was observed (14 and 2 mm, respectively). This period corresponds to the final stages of generative organ development – seed filling and fruit maturation. The calculated hydrothermal coefficient confirmed the dry nature of the season, and in the second half of the growing period, even severely dry conditions prevailed, creating water stress for plants.

It is well known that in leguminous woody species, soil moisture deficit after fertilization significantly affects the course of embryogenesis, promotes abortion of a portion of seeds, and reduces their mass due to limited assimilate supply (Farooq et al., 2015; Shen et al., 2018). For *L. anagyroides*, this pattern is particularly characteristic, as evidenced by the high variability of seed set in pods and the significant proportion of underdeveloped seeds reported in the literature (Szentesi, 2006).

The average thousand-seed weight in the studied samples was 8.54 g, which is substantially lower than the values reported in international databases and floristic reviews (≈30–34 g) (Szentesi, 2006; Rembert, 1996). At the same time, variability between replicates was low, indicating internal consistency of the results. This discrepancy with literature data may be explained by several factors. First, reference sources typically report seed mass for samples dried to constant weight, whereas in the present study measurements were conducted on working material. Second, climatic conditions of the year – particularly moisture deficit in the second half of the growing season – likely limited the accumulation of storage substances in seeds. Third, the influence of genetic characteristics of the studied plant cannot be excluded, as introduced species often exhibit increased variability in generative traits.

Analysis of fruit structure showed that the average number of seeds per pod was 1.95, with a predominance of low-seeded fruits containing one to two seeds. This result is consistent with the findings of Á. Szentesi (2006), who demonstrated that although the species is potentially capable of forming 6–8 seeds per pod, in practice only about two fully developed seeds are produced due to abortion of the remaining ovules. Therefore, the obtained value should be interpreted not as a reduction in reproductive capacity, but as an expression of a biological characteristic of the species, intensified by unfavorable weather conditions of the year.

An important indicator is also the yield of fully developed seeds, which in this study amounted to approximately 27% of the total mass of collected material. This level indicates a substantial proportion of pod shells, empty, or underdeveloped seeds, which again corresponds with the low number of seeds per pod and the known features of the species' reproductive biology (Rembert Junior, 1996). The precipitation deficit in August–September, when final seed development occurs, likely intensified the gap between potential and actual seed productivity.

In summary, it can be stated that under the conditions of the Sumy region in 2024, the limiting factor in the realization of the seed potential of *L. anagyroides* was not the temperature regime, but water availability during the second half of the growing season. The obtained indicators of seed weight, number of seeds per pod, and yield of fully developed seeds are a logical consequence of these conditions and are consistent with literature data for the species (Poșta, 2018; Poșta & Florin, 2017).

Traditional methods of propagation of *L. anagyroides* are characterized by a number of limitations, especially under conditions of introduction (Sato et al., 1995). Seed propagation remains the main and biologically justified method of species reproduction (Poşta et al., 2017); however, it requires optimization of pre-sowing treatment techniques, which highlights the relevance of further research aimed at increasing seed productivity and developing effective propagation methods under the conditions of the Left-Bank Forest-Steppe of Ukraine.

The conducted study made it possible to establish the main patterns in the formation of seed productivity of *L. anagyroides* under the conditions of the Left-Bank Forest-Steppe of Ukraine. The obtained results indicate a complex and multifactorial nature of generative development, in which climatic conditions, particularly the hydrothermal regime of the growing season, play a decisive role.

It was determined that the water factor is the key limiting element in the realization of potential seed productivity. The dry conditions of the second half of summer 2024, characterized by a low hydrothermal coefficient (HTC = 0.42), significantly affected the processes of seed filling and maturation. As a result, a decrease in thousand-seed weight to 8.54 g was observed, indicating insufficient seed filling and limited accumulation of storage substances.

Structural analysis of fruits revealed the predominance of one- and two-seeded pods, which is a characteristic feature of incomplete realization of reproductive potential. The average number of seeds per fruit was 1.85, confirming the tendency toward reduction of a portion of ovules during development. This is likely a consequence of intensified competition for assimilates under moisture deficit, especially at the final stages of organogenesis.

The yield of fully developed seeds was approximately 27%, indicating a significant proportion of underdeveloped or shriveled seed material. This level of realization of generative potential can be assessed as partial and limited by unfavorable environmental factors. At the same time, the absence of critical temperature deviations during the growing season allows us to conclude that moisture deficit, rather than temperature regime, was the primary limiting factor.

Thus, the obtained results confirm the strong dependence of seed productivity of *L. anagyroides* on moisture conditions and emphasize the necessity of considering climatic factors in its introduction, cultivation, and assessment of reproductive capacity. The practical significance of the study lies in the possibility of using the identified patterns to predict seed productivity under climate change conditions, as well as to optimize agronomic practices aimed at improving seed quality.

REFERENCES

1. Botanical Society of Britain & Ireland (BSBI). (1998). *Laburnum anagyroides* Medik. ‒ Species account. Access mode: https://fermanagh.bsbi.org/laburnum-anagyroides-medik?utm_source=chatgpt.com
2. Csurhes, S., Markula, A. (2016). Invasive plant risk assessment: Golden chain tree (*Laburnum anagyroides*). Biosecurity Queensland. Access mode: https://www.dpi.qld.gov.au/__data/assets/pdf_file/0015/76110/IPA-Golden-Chain-Tree-Risk-Assessment.pdf?utm_source=chatgpt.com
3. Didkivska, S. V. (2021). Viburnum×bodnantense aberc. ex stearn v kulturi. [Viburnum × bodnantense Aberc. ex Stearn in cultivation]. Roslyny ta urbanizatsiia: Materialy desiatoi Mizhnarodnoi naukovo-praktychnoi konferentsii «Roslyny ta urbanizatsiia» (Dnipro, 3 bereznia 2021 r.). Dnipro. 208. 121. (in Ukrainian).
4. EUNIS (2025). Alcareous rocky slopes with chasmophytic vegetation (habitat description). European Environment Agency. Access mode: https://eunis.eea.europa.eu/habitats/10165?utm_source=chatgpt.com
5. Farooq, M., Hussain, M., Wahid, A., & Siddique, K. H. M. (2015). Drought stress in plants: An overview on physiological, biochemical and molecular responses. Plant Responses to Drought Stress, 1–33. doi: https://doi.org/10.1007/978-3-642-32653-0_1
6. Ferner, R. (1998). Poisonous Plants and Fungi in Britain: Animal and Human Poisoning, 2nd edn. Journal of the Royal Society of Medicine. doi: https://doi.org/10.1177/014107689809100822.
7. FloraVeg / Euro+Med. (2025). Laburnum anagyroides – taxon overview (traits, distribution, vegetation context). Access mode: https://floraveg.eu/taxon/overview/Laburnum%20anagyroides?utm_source=chatgpt.com
8. Hartmann H. T., Kester D. E., Davies F. T., Geneve R. L. (2010). *Plant Propagation: Principles and Practices.* 8th ed. Upper Saddle River, NJ: Prentice Hall, 915.
9. Hill M. O., Mountford J. O., Roy D. B., Bunce R. G. H. (2000) Extending Ellenberg's indicator values to a new area: an algorithmic approach. Journal of Applied Ecology. 37(1). 3–15. doi: https://doi.org/10.1046/j.1365-2664.2000.00466.x
10. ISTA (2024). International Rules for Seed Testing. International Seed Testing Association. Access mode: https://www.seedtest.org/api/rm/882F39FEQGF349B/ista-rules-2024-00-introduction-final.pdf
11. Jach, M. E., Sajnaga, E., Wójcik, M. (2022). Utilization of legume–nodule bacterial symbiosis in recovery of contaminated lands. International Journal of Environmental Science and Technology. 19. 987–1002. doi: 10.3390/біологія11050676.
12. Łotocka, B. (2024). Structure of root nodules in *Laburnum anagyroides* Medik. Acta Biologica Cracoviensia. Series Botanica. 2024. 66(1). P. 45–56. doi: 10.5586/aa/176077
13. Mamchur, T.V.. Muskan, V.S. (2023). Biolohichni osoblyvosti *Laburnum anagyroides* Medik. v umovakh studmistechka umanskoho nus ta yoho vykorystannia. [Biological characteristics of *Laburnum anagyroides* Medik. under the conditions of the campus of Uman National University of Horticulture and its use]. Suchasni problemy biolohii v umovakh zmin klimatu: Mater. Vseukrainskoi naukovoi Internet-konferentsii (7 lypnia 2023 roku). Uman: Umanskyi NUS. 55‒58. (in Ukrainian).
14. Pakhomov, O. Ye., Opanasenko, V. F., Kabar, A. M., Rusetska, L. L. (2008). Pidsumky introduktsii derevno-chaharnykovykh roslyn v arboretumi Botanichnoho sadu Dnipropetrovskoho universytetu. [Results of the introduction of woody and shrubby plants in the arboretum of the Botanical Garden of Dnipro University].Visnyk Dnipropetrovskoho universytetu. Biolohiia. Ekolohiia. 16(2). 131–136. (in Ukrainian).
15. Paolicchi, F., Tani, C., Giannini, R. (2003). In vitro culture of immature embryos of *Laburnum anagyroides*. Plant Cell, Tissue and Organ Culture. 75. 77–83. doi: https://doi.org/10.1023/A:1024602315226
16. Piskun, N. L. (2013). Porushennia tverdonasinnosti *Laburnum anagyroides* Medik. та *Laburnum alpinum* Mill. [Breaking seed dormancy of *Laburnum anagyroides* Medik. and *Laburnum alpinum* Mill.]. Naukovyi visnyk NLTU Ukrainy. 23(6). 138‒142. (in Ukrainian).
17. Poçta S., Florin, A. (2017). Reproductive biology and regeneration of *Laburnum anagyroides* in Central Europe. Journal of Forest Science. 63(4). 145–152. doi: https://doi.org/10.17221/89/2016-JFS
18. Poșta, D. S. (2018). Researches regarding the influence of the nutritive mixture on the growth of *Laburnum anagyroides* Med. (*Cytisus laburnum* L.) species in container conditions. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture,* 75(1). 59–63.
19. Poşta, D. S., & Sala, F. (2017). Influence of seed treatment on germination in *Laburnum anagyroides* Med. Revista Botanică. 14(1). 22‒28.
20. POWO. (2021). Plants of the World Online: *Laburnum anagyroides* Medik. Royal Botanic Gardens, Kew. Access mode: https://powo.science.kew.org/taxon/urn%3Alsid%3Aipni.org%3Anames%3A501428-1?utm_source=chatgpt.com
21. Rembert Junior, D. H. (1996). Megasporogenesis in *Laburnum anagyroides* Medic. a case of bisporic development in Leguminosae. Transactions of the Kentucky Academy of Science. 27. 47‒50
22. Sajnaga, E., & Jach, M. E. (2020). Bradyrhizobia associated with *Laburnum anagyroides*, an exotic legume grown in Poland. Symbiosis. 80(3). 245‒255.

23. Sato, H., Tahara, S., Ingham, J. L., & Dziedzic, S. Z. (1995). Isoflavones from pods of Laburnum anagyroides. Phytochemistry. 39(3). 673–676. Access mode: https://www.sciencedirect.com/science/article/pii/0031942295000297?utm_source=chatgpt.com.
24. Shen, H., Li, Z., & Wang, Z. (2018). Effects of water deficit on seed development and abortion in leguminous plants. Plant Physiology and Biochemistry, 130, 273–281. https://doi.org/10.1016/j.plaphy.2018.07.012
25. Shlapak, V. P. Piskun, N. L. (2007). Morfolohichni osoblyvosti *Laburnum anagyroides* Medik. v umovakh Pravoberezhnoho Lisostepu Ukrainy. Naukovyi visnyk, 17.7. 7–11. (in Ukrainian).
26. Stawiarz, E., & Wróblewska, A. (2013). Flowering dynamics and pollen production of *Laburnum anagyroides* Med. under the conditions of south-eastern Poland. Journal of Apicultural Science. 57(2). 103.
27. Stępkowski, T., Watkin, E., McInnes, A. (2018). Phylogeny and phylogeography of rhizobial symbionts associated with legumes of the tribe Genisteae // Systematic and Applied Microbiology.41(5). 473–486. doi: 10.3390/гени9030163
28. Szentesi, A. (2006) Seed predation and seed abortion in *Laburnum anagyroides.* Acta Oecologica. 29. 125–132. doi: https://doi.org/10.1016/j.actao.2005.10.002.
29. Szentesi, A., Wink, M. (1991). Fate of quinolizidine alkaloids through three trophic levels*: Laburnum anagyroides (Leguminosae)* and associated organisms. J Chem Ecol. 17(8). 1557–1573.
30. Trees and Shrubs Online (2024). *Laburnum anagyroides:* ecology and cultivation notes (alkaline soils, warmer/drier sites). Access mode: https://www.treesandshrubsonline.org/articles/laburnum/laburnum-anagyroides/?utm_source=chatgpt.com.

PECULIARITIES OF CULTIVATING *ACER PLATANOIDES* L. PLANTING MATERIAL UNDER THE CONDITIONS OF THE NORTH-EASTERN FOREST-STEPPE OF UKRAINE

Anhelina Dudka
PhD in Agricultural Sciences, Associate Professor of the Department of Landscape Gardening and Forestry, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0001-9444-4339

Forests play a fundamental role in maintaining ecological equilibrium, regulating climate, and ensuring the socio-economic well-being of society. They occupy approximately 16 % of the territory of Ukraine; however, this indicator remains below the optimal level for a temperate climate (25–30 %), indicating a necessity for expanding forest areas, particularly through the establishment of highly productive stands [4].

According to estimates, one hectare of mature forest sequesters an average of 10–12 tons of CO_2 annually, rendering forest plantations a key instrument in mitigating climate change [31, 33, 38].Highly productive stands ensure not only economic benefits but also long-term ecological stability. In such forests, the annual wood increment can reach 6–8 m^3/ha, which is twice the average indicators for natural forests in the Polissia and Forest-Steppe regions of Ukraine. They serve as the foundation for continuous forest management, carbon stock formation, and soil protection against erosion. Research results indicate that the creation of highly productive pine cultures with an admixture of deciduous species increases the growing stock by 15–20 % compared to monocultures of the same age [42].

The relevance of afforestation in Ukraine is driven by the need for eco-adaptive forest restoration, which serves as the primary method for increasing the state's forest cover under conditions of global anthropogenic landscape transformation [16]. The establishment of new forest massifs requires a scientifically justified selection of species that correspond to specific forest-growing conditions and ensure maximum ecological impact. In this context, an important aspect involves modeling the optimal carbon accumulation specifically in mixed, uneven-aged forests, where the structural complexity of the phytocenosis allows for a stable balance between carbon sequestration and biomass productivity [1].

Special attention should be given to the role of mixed stands. Traditionally, pure forests – pine, oak, or spruce monocultures – predominated in Ukraine. However, contemporary research demonstrates that they are less resilient to climate change, pests, and windthrows. In contrast, mixed forests form a more complex structure, ensuring a more uniform microclimate and a more stable soil cover. The mixing of species enhances resource-use efficiency, particularly concerning water and nutrients, which positively influences biomass productivity [5, 14].

Mixed forests involving broad-leaved species such as common oak (*Quercus robur*), Norway maple (*Acer platanoides*) and small-leaved lime (*Tilia cordata*) contribute to the improvement of the physicochemical properties of the soil. Studies show that the organic matter content in the upper soil layer under mixed stands is 20–25 % higher than under pure pine cultures, creating favorable conditions for the development of mycorrhiza and microflora. This, in turn, enhances natural fertility and reduces the requirement for fertilizer application [23].

In addition to improving soil conditions, the incorporation of companion species into shelterbelts and forest strips is of critical importance for modern apiculture. In particular, the nectar and pollen potential of woody species such as maple and linden provides a stable forage base for entomofauna, thereby contributing to increased crop yields in adjacent agricultural landscapes [35]. Thus, mixed forest stands function as biological reservoirs, supporting the activity of natural pollinators within the Forest-Steppe zone.

Norway maple, although not classified as a principal forest-forming species, plays a significant ecological and bioengineering role within mixed forest ecosystems. Its root system enhances soil stabilization and prevents erosion processes, while its dense canopy contributes to the formation of a stable microclimate beneath the forest cover. Moreover, maple serves as an additional nectar source for pollinators and provides habitat for invertebrates and avifauna. Empirical data indicate that in pine–maple stands, understory biodiversity is approximately 30 % higher than in pure pine stands of the same age [20, 32].

From an economic perspective, the admixture of broadleaved species in coniferous plantations improves timber quality and reduces the risk of simultaneous stand mortality due to pests or wildfires. For example, in mixed stands, the proportion of pest-damaged trees is 40 % lower compared to pure pine forests. This effect can be attributed to the "resource dilution" phenomenon in pest trophic bases and the enhanced moisture-retention capacity of the understory [49].

From an organizational and economic standpoint, the planning of such forest establishment is not feasible without the development of a network of permanent nurseries. The design and implementation of plans for specialized ornamental and forest nurseries, particularly within individual forestry enterprises, ensure the production of high-quality planting material with predictable survival rates [30]. This creates a reliable foundation for large-scale afforestation and land reclamation programs.

In addition to increasing resilience, the inclusion of broadleaved species contributes to the stabilization of the soil nitrogen balance. The litter of maple and linden decomposes more rapidly, enriching the upper soil horizons with bioavailable forms of nitrogen and potassium, which is particularly important for young pine stands on sandy soils. Field studies have shown that the introduction of 10–15 % share of maple increases the average annual increment of pine by 8–12 %, due to improved nitrogen nutrition and soil moisture retention [13].

Highly productive mixed stands also demonstrate a greater capacity for carbon sequestration. Studies indicate that forests composed of three or more tree species contain 25–30 % higher carbon stocks in aboveground biomass compared to monocultures of the same age class. This underscores the importance of mixed forest establishment as a key component of Ukraine's national climate strategies. Specifically, increasing the proportion of mixed stands by 10 % may result in an additional sequestration of approximately 1.8 million tons of CO_2 annually [8, 44].

The study of biomass accumulation mechanisms shows that mixed stands are better adapted to water stress conditions. In the context of climate change, the ability of maple and other broadleaved species to maintain optimal soil water regimes becomes critical for the survival of the coniferous component. Research confirms that the resource-use efficiency of such ecosystems increases due to niche differentiation among root systems of different tree species [14, 29].

Equally important is the aesthetic and recreational value of such forests. Mixed stands exhibit more pronounced seasonal color dynamics and create an attractive environment for public recreation [41]. According to sociological surveys, 68 % of respondents prefer mixed forests over monocultures, indicating the potential for integrating productive and cultural functions of forests in contemporary forest management [28, 24, 41].

The aesthetic appeal of mixed forests is also closely associated with the psychological comfort of visitors in urbanized areas. The establishment of park zones using various maple species enables the creation of landscapes with high chromatic diversity during the autumn period, positively influencing the recreational evaluation of urban green spaces [24]. This highlights the necessity of integrating silvicultural approaches into urban planning.

In conclusion, the establishment of highly productive mixed forest stands, incorporating not only principal but also auxiliary species such as Norway maple, represents a strategic direction for the development of Ukraine's forestry sector [18]. The combination of coniferous and broadleaved species ensures an optimal balance between productivity, resilience, and ecological stability of forest ecosystems. Such an approach aligns with contemporary principles of sustainable forest management and contributes to the formation of long-lived, climate-adapted forests for future generations [19].

The analysis of long-term experience in the cultivation of mixed forest stands indicates that the success of reforestation is directly dependent on the quality of the seed material used and the technologies applied for its pre-sowing treatment [3, 11]. The application of modern seedling growth intensification techniques in combination with mycorrhization creates favorable conditions for the formation of resilient forest ecosystems of the future. The implementation of innovative solutions in forest nursery practices is a key prerequisite for achieving the target forest cover indicators of Ukraine [30, 45].

Maples (*Acer spp.*) occupy an important niche in the forest ecosystems of Ukraine, particularly Norway maple, sycamore maple (*Acer pseudoplatanus*), and field maple (*Acer campestre*). Although they are not classified as principal forest-forming species, their share in the overall forest composition of the country reaches 3–5 %. In the Forest-Steppe zone and the Carpathians, maples constitute an essential component of mixed stands. They play a significant ecological role in stabilizing forest ecosystems by improving soil properties, contributing to understory formation, and supporting biodiversity conservation [48, 15].

From an ecological perspective, maple species play a substantial role in maintaining soil fertility. Their leaf litter decomposes rapidly, forming humus that enriches upper soil horizons with organic compounds of nitrogen, calcium, and potassium. Studies have shown that soils under maple stands contain 25–30 % higher humus content compared to pure pine plantations. Consequently, maple functions as a natural "biofertilizer," enhancing soil structure and permeability [7, 9].

Norway maple is characterized by high shade tolerance and frost resistance, making it an effective component of mixed forests in the northern Forest-Steppe zone. Its deep root system contributes to soil stabilization, preventing erosion on slopes and in riparian areas. Research conducted by Ukrainian forestry scientists has demonstrated that the inclusion of 10–20 % maple in pine stands increases their resistance to windthrow by 15–18 % and reduces drought-related losses [46].

One of the key aspects of maple's ecological significance is its influence on the microclimate of forest ecosystems. Due to its dense canopy, it provides shading and reduces the temperature beneath the forest canopy by 2–4°C, which positively affects understory growth and soil moisture conservation. In mixed stands containing maple, soil surface evaporation is reduced by up to 20 %, which is particularly important for forests in the Forest-Steppe zone with a moderately continental climate [7].

Maple also holds considerable economic value due to the favorable physical and mechanical properties of its wood. It is hard, dense, fine-textured, and exhibits a light luster, making it a valuable raw material for the production of furniture, musical instruments, parquet flooring, and decorative elements. Its bending strength exceeds that of pine by 30–35 %, and its hardness by approximately 40 % [10, 25]. In Ukraine, maple wood is widely utilized in the furniture and plywood industries, particularly in the Volyn, Lviv, and Cherkasy regions.

In addition to its industrial importance, maple stands play a vital role in sanitary-protective and recreational afforestation. Maple effectively absorbs dust and nitrogen oxides from the air, contributing to the purification of urban ecosystems. One hectare of maple plantation can absorb up to 80 kg of dust and 40 kg of gaseous pollutants annually. For this reason, maple is widely used as a principal species in the establishment of green belts around cities and along transportation corridors [28].

Its importance as a melliferous plant is also well recognized. The flowering of Norway maple provides early spring nectar, supporting pollinator populations after winter dormancy. One hectare of flowering maple forest can yield up to 100 kg of nectar, making it an important component of ecological networks within agricultural landscapes. This integration of forestry and apiculture enhances biodiversity and promotes the sustainable use of natural resources [17].

Within mixed stands, maple also functions as a biological "buffer" species for the main tree components. It mitigates environmental stresses by creating more stable growth conditions for coniferous species. In pine–maple stands, for instance, a more balanced soil water regime is observed, reducing the risk of seedling mortality during drought years. Studies have shown that the inclusion of broadleaved species in coniferous stands increases overall forest productivity by 10–25 % [22].

Furthermore, maple plays an important role in the conservation of genetic resources and ecosystem stability. Its seeds are effectively dispersed by wind, facilitating natural regeneration on clear-cut areas and forest gaps. This trait allows maple to be used as a pioneer species in the reclamation of degraded lands and in the establishment of protective forest belts. It has been documented that on technogenically disturbed soils, the survival rate of maple seedlings exceeds 85 %, surpassing that of oak and ash [50].

Within the complex of national economic functions, maple forests and their admixtures possess long-term economic and ecological value. They contribute to ecosystem stability, enhance the productivity of dominant species, improve soil and air quality, and contribute to the aesthetic value of natural landscapes. In the long term, maple must remain one of the key associate species within the structure of mixed stands, particularly in programs aimed at adapting Ukrainian forestry to climate change [26].

The cultivation of high-quality Norway maple planting material is a critical prerequisite for the successful establishment of mixed and protective forest stands. Given that this species is characterized by slow initial growth, the precise selection of sowing dates, seed placement depth, and the application of fertilizers and growth regulators significantly influence seedling survival rates and the formation of a robust root system [11, 21].

Seeds of Norway maple exhibit a deep dormancy period lasting 4–6 months. To obtain uniform germination, stratification is required, involving the storage of seeds in moist sand at a temperature of +2 to +5°C for 90–120 days. Field experiments have demonstrated that cold stratification increases germination rates from 42 % to 88 %, while seedling emergence occurs 10–12 days earlier compared to non-stratified control variants [27, 44].

Regarding sowing time, the best results are achieved with autumn or early spring sowing. Autumn sowing (October–early November) allows seeds to undergo natural stratification in the soil, resulting in uniform emergence in spring. However, in the absence of sufficient snow cover, there is a risk of seed frost damage. Therefore, in the northern regions of Ukraine, spring sowing following artificial stratification is preferable. The optimal sowing depth for Norway maple seeds ranges from 2.5 to 4 cm, depending on soil texture. On light sandy soils, seeds are sown deeper (up to 4 cm) to prevent desiccation, whereas on loamy soils, the depth should not exceed 2.5 cm to ensure rapid germination. Burial deeper than 5 cm reduces germination by more than 20 % due to the mechanical difficulty of cotyledon emergence. The optimal seeding density is 5–6 g/m², providing approximately 350–400 seedlings [3].

Soil preparation is a critical factor. Maple exhibits optimal growth on fertile loamy and sandy loam soils with a pH of 6.0–7.0. Prior to sowing, deep plowing (25–30 cm) and cultivation are performed, followed by the application of mineral fertilizers at rates of 40–60 kg/ha nitrogen, 60–80 kg/ha phosphorus, and 40 kg/ha potassium. The application of organic fertilizers (10–15 t/ha of humus) improves soil structure and water-holding capacity [29].

To stimulate seed germination, growth regulators of natural origin are widely used. Pre-sowing treatment with gibberellin solutions (25 mg/L) or succinic acid (100 mg/L) accelerates germination by 5–7 days and increases germination energy by 15–20 %. The use of biostimulants such as “Epin-Extra” or potassium humate promotes better development of the primary root system and reduces sensitivity to moisture fluctuations. On average, seedling survival increases from 78 % to 92 % under such treatments [6, 36, 39].

Seedling care includes regular soil loosening, weed control, and maintenance of optimal soil moisture. During drought periods, irrigation is applied at a rate of 200–250 m³/ha to prevent surface crust formation [29]. To enhance irrigation efficiency, hydrogels–polymeric substances capable of retaining water in the root zone–are used. The application of hydrogels at a rate of 30 kg/ha reduces irrigation frequency by 25–30 % without compromising seedling productivity [45, 36].

Mycorrhization is of particular importance, involving the inoculation of seedling roots with fungi such as *Pisolithus tinctorius* or *Laccaria laccata*. These fungi form symbiotic associations that enhance nutrient availability and increase resistance to pathogens. Studies conducted in the Zhytomyr forestry enterprise have shown that mycorrhization increased the survival rate of Norway maple seedlings from 74 % to 91 %, and the average plant height in the first year from 12.4 cm to 16.7 cm [12, 34, 47].

An additional practice to improve planting material quality is the application of anti-stress growth regulators during transplanting. The use of “Zircon” or “Radifarm” at concentrations of 0.1–0.2 % during transplantation reduces root damage losses by 20–25 %. These treatments facilitate faster adaptation of seedlings to new conditions and stimulate the formation of secondary roots [2, 40].

One year after sowing, seedlings reach an average height of 20–25 cm with a stem diameter of 3–4 mm. In nurseries applying intensive cultivation technologies (irrigation, fertilization, mycorrhization), these parameters may be 30–35 % higher [43]. Seedlings suitable for outplanting are those with a well-developed root system, an unbranched main root, and a height-to-diameter ratio not exceeding 8:1.

Thus, the technology for cultivating Norway maple planting material is based on an integrated approach combining physiological, agronomic, and biotechnological methods. The most critical factors include seed stratification, optimal timing and depth of sowing, application of organo-mineral fertilizers, and the use of growth biostimulants. Adherence to these principles ensures the production of healthy, viable planting stock with survival rates exceeding 90 %, which is a prerequisite for the establishment of resilient, productive, and climate-adapted forest stands [2, 37].

Research Conditions. The research was conducted on the basis of the Krasnopillia Forestry Branch of the State Specialized Enterprise “Forests of Ukraine,” which functions as a structural subdivision of the State Enterprise “Forests of Ukraine.” The administrative location of the branch is: 42400, Ukraine, Sumy Oblast, Sumy District, urban-type settlement Krasnopillia, 6 Kalinina Street.

The State Enterprise “Krasnopillia Forestry” occupies a significant position in the economic development of the Krasnopillia district at the present stage. Its history dates back to 1935. The enterprise is territorially located in the eastern part of Sumy Oblast and encompasses lands within the Krasnopillia, Sumy, and Trostianets districts, covering a total area of 23,235 hectares.

Organizationally, the enterprise includes five forest districts, as well as a number of production and auxiliary units. These comprise a wood-processing workshop, a lower timber yard, an in-house vehicle fleet, repair facilities, and an apiary. The principal forest-forming species underpinning forest management activities include oak, ash, maple, and pine. The allowable annual cut for final fellings is established at 36.6 thousand m³. The annual area of clear-cutting operations amounts to 90–100 hectares, while thinning and sanitary fellings are conducted annually over an area of 750–770 hectares.

The average number of employees engaged in the forestry enterprise is 223. Considerable attention is devoted to reforestation and sustainable forest management practices. Annually, new forest plantations are established over an area of 90–100 hectares. To support this process, a permanent nursery with a total area of

8.7 hectares operates within the Velykobobrytske forest district. This nursery produces planting material of key forest-forming species (seedlings of oak, ash, pine, spruce, and linden), as well as a wide range of ornamental plants. Ornamental species include seedlings and saplings of thuja, juniper, boxwood, chestnut, spruce, barberry, and others. Additionally, ground-cover (carpet-forming) plants are cultivated in specialized greenhouses and nursery plots.

Territorially, the branch is located in areas with relatively high forest cover; in the Krasnopillia district, it reaches 24.1 %, with forest stands distributed relatively evenly. The enterprise plays an important role in meeting regional timber demand, satisfying approximately 80 % of local needs. For example, in 2016, more than 53.08 thousand m³ of merchantable timber were harvested, of which over 27.17 thousand m³ constituted industrial wood.

The temperature regime of the Krasnopillia district, located within the Eastern Forest-Steppe zone of Ukraine, is a key ecological factor determining both biological processes (vegetation period, growth intensity) and the agro-technical feasibility of forestry operations. The region is characterized by a moderately continental climate with pronounced seasonality and significant annual temperature amplitudes. The mean annual air temperature typically ranges between 6.5 and 7.5°C, with a tendency toward increase due to global climate change. January is the coldest month, with average temperatures ranging from –6.0 to –8.0°C. Absolute minima may drop to –30°C or lower, posing a risk of frost damage to young, non-adapted seedlings of Norway maple and limiting its cultivation.

The vegetation period, defined by a mean daily air temperature exceeding +5°C, lasts on average 200–210 days, beginning in the first half of April and ending in the second half of October. This period is critical for conducting major operations in forest nurseries and plantations. The sum of active temperatures (above +10°C), which determines photosynthetic activity and biomass accumulation, amounts to approximately 2600–2800°C. This thermal resource is sufficient for the successful production of standard planting material of Norway maple, although it necessitates optimization of sowing dates and the use of growth regulators.

The transition of temperature above +10°C in spring serves as a signal for intensive seedling growth and determines optimal planting periods. Rapid temperature increases in May (mean monthly temperatures reaching +15 to +18°C) promote high survival rates but simultaneously increase the risk of early summer droughts, particularly affecting seedlings with imbalanced root-to-shoot ratios.

The summer period is characterized by average temperatures of +19 to +22°C (July). However, the increasing frequency of extreme temperatures (up to +35°C), combined with low soil moisture, intensifies thermal stress and necessitates the application of drought-resistance-enhancing technologies, including the use of high-quality planting material with increased root collar diameter and optimal root system coefficients.

The autumn period is crucial for seedling hardening prior to winter, involving the accumulation of starch and other protective compounds. Sharp temperature declines in October–November to sub-zero values may damage plants that have not completed vegetation. Therefore, analysis of the temperature regime is fundamental for adapting technological solutions in forestry, particularly in determining optimal application rates of growth regulators.

The moisture regime directly influences soil water balance, plant transpiration intensity, and overall forest ecosystem productivity. The Krasnopillia district, located within a zone of sufficient but unstable moisture in the Eastern Forest-Steppe, is characterized by pronounced seasonal unevenness in precipitation.

The average annual precipitation ranges between 500 and 550 mm, which is theoretically sufficient to meet the needs of forest stands. Approximately 65–75 % of annual precipitation falls during the warm period (April–October), which is favorable for vegetation.

The spring period (April–May) is often characterized by insufficient precipitation, leading to soil moisture deficits at the beginning of the growing season. This is particularly critical for newly planted seedlings, as it slows their establishment and growth. In summer (June–August), precipitation peaks in July but is typically torrential, resulting in high surface runoff and low infiltration rates. Consequently, despite high monthly precipitation totals, a significant portion of water does not remain in the root zone, increasing the risk of soil drought between rainfall events.

To objectively assess moisture conditions, the Selyaninov's hydrothermal coefficient (HTC) is used, representing the ratio of precipitation during periods with temperatures above +10°C to the sum of active temperatures. In the Krasnopillia district, HTC values typically range from 1.0 to 1.2, corresponding to a zone of sufficient moisture. However, the increasing frequency of atmospheric and soil droughts in recent years may reduce HTC values, especially during critical summer months. This necessitates higher requirements for planting material quality, particularly seedlings with a high root-to-shoot ratio to improve water-use efficiency and drought resistance.

The soil cover of the Krasnopillia district, typical of the Eastern Forest-Steppe, is a key edaphic factor determining forest productivity, particularly for Norway maple. The dominant soils are typical chernozems and grey forest soils, formed on loess parent material under moderately continental climatic conditions and alternating meadow and forest vegetation.

Typical chernozems occupy watershed plateaus and exhibit the highest natural fertility. Their main characteristics include a deep humus horizon (up to 70–100 cm), high humus content (4–6 %), and a stable granular structure providing optimal water-air regime. These soils are highly suitable for Norway maple, promoting the development of a strong root system and rapid aboveground growth.

At the same time, significant areas, particularly on elevated relief elements and under long-established forests, are occupied by grey forest soils formed through podzolization processes. These soils are characterized by a thinner humus horizon (30–40 cm) and lower humus content (1.5–3.5 %) compared to chernozems. A distinctive feature is profile differentiation into eluvial (leached) and illuvial (clay-enriched) horizons, often resulting in periodic waterlogging in spring and rapid drying during summer droughts.

On slopes and in ravines, sod-podzolic soils and meadow-chernozem soils may also occur, the latter associated with depressions and characterized by gleyed horizons due to shallow groundwater levels.

From a forestry perspective, the predominantly medium loamy texture of soils in the region is favorable, ensuring adequate water permeability and moisture retention. However, grey forest soils require particular attention, as their tendency toward compaction and temporary waterlogging may adversely affect root system development. Therefore, the implementation of agrotechnical measures aimed at improving soil aeration and structure, along with the use of high-quality planting material capable of withstanding stress conditions associated with soil heterogeneity, is essential for successful afforestation in the Krasnopillia district.

The production of high-quality planting material of Norway maple at the permanent nursery of the Velykobobrytske forest district of the Krasnopillia Forestry Enterprise is an essential component of meeting the silvicultural demands of the enterprise, as maple represents one of the associated species used in forest stand formation. Under Forest-Steppe conditions, where flat (non-ridge) sowing on fertile soils predominates, primary attention is given to proper seed preparation, optimal sowing dates and patterns, enabling maximization of standard seedling output within a single vegetation period.

Considering that the soils of the nursery fields include chernozems and grey forest soils, the pre-sowing soil preparation system is aimed at creating a loose soil layer and preserving moisture. On heavy, compacted plots, deep tillage using moldboardless plowing is required, followed by cultivation and harrowing. To level the surface and break down large soil clods prior to sowing, soil milling using FPSh-1.3 rotary tillers was applied, while light rolling with ZKVG-1.4 rollers was used to ensure soil compaction and facilitate capillary moisture rise.

For sowing, first-class quality seeds are used, which do not require prolonged stratification. Under Forest-Steppe conditions, preference is given to autumn sowing of Norway maple, as seeds sown in autumn undergo natural stratification and produce earlier and more uniform emergence, allowing seedlings to establish before the onset of summer droughts – a critical factor for the region. Seeds are sown in a dry state approximately 1.5–2 months prior to stable soil freezing. In cases where spring sowing is required, seeds must be stratified for 90 days in trenches or storage facilities in a mixture with moist sand. Prior to sowing, treated seeds are disinfected with systemic fungicides approved for forestry use to protect against fungal diseases, particularly fusariosis.

The seeding rate for Norway maple is 12 g per linear meter of furrow. The sowing depth should be maintained within 2–4 cm, which is optimal for relatively large seeds in loamy soils typical of the region and ensures adequate moisture availability. Sowing is carried out manually using a banded three-row patterns, allowing for efficient mechanization of subsequent maintenance operations.

Following emergence, seedlings – being sensitive to late spring frosts – require protection through the application of smoke screens or short-term fine-spray irrigation. The complex of tending operations includes weed control and soil loosening, which are performed simultaneously. Effective weed management is achieved through a combination of mechanical and chemical methods. To prevent soil crust formation and preserve moisture in the upper soil layer after rainfall or irrigation, post-emergence loosening with light harrows is conducted.

Norway maple seedlings typically reach standard parameters (stem diameter not less than 3 mm and height not less than 15 cm) within one year, making them suitable for outplanting in forest stands during the following growing season.

Research Objective. The objective of this study is to determine optimal sowing periods and evaluate the effectiveness of growth regulator application for intensifying growth and improving the quality of planting material of Norway maple under the conditions of Krasnopillia Forestry.

Object of Research. The object of research is the process of formation of qualitative characteristics of Norway maple planting material depending on sowing dates and the application of growth regulators.

Subject of Research. The subject of the study includes: sowing periods (September, October, November); sowing depth (1 cm, 2 cm); growth regulator treatments (Biosyl and control); morphometric parameters (height, root collar diameter, root length); phytomass ratio; and field germination.

Research Tasks. To achieve the stated objective, the following tasks were formulated:

To determine the effect of different sowing periods (September, October, November) and sowing depths on field germination of Norway maple seeds.

To study morphometric parameters (height, root collar diameter, root length) of one-year-old seedlings depending on sowing periods and seed treatment with growth regulators.

To determine the ratio of aboveground to belowground phytomass of seedlings to assess their adaptability and environmental resilience.

Research Methods. A comprehensive system of complementary methods was applied to ensure an objective assessment of the effects of sowing time optimization and growth regulator application on planting material quality. The visual method was used for systematic observations of phenological growth and development stages. The measurement-weight method was applied to determine key morphometric parameters, including seedling height, root collar diameter, main root length, as well as aboveground and belowground biomass for calculating their ratio. Mathematical and statistical analysis was conducted using analysis of variance (ANOVA) to determine the significance of differences between experimental treatments and to evaluate the contribution of each studied factor (sowing period, growth regulator, and their interaction).

Research Results. Despite the fact that Norway maple is not classified as a principal forest-forming species in the Forest-Steppe zone of Ukraine, it plays a significant role in shaping biodiversity, enhancing the resilience of forest ecosystems, and improving the qualitative characteristics of timber from dominant tree species. As an accompanying species, Norway maple is a valuable melliferous plant, contributes to the improvement of soil conditions through the rapid decomposition of leaf litter, and provides additional protection against soil erosion.

Contemporary challenges associated with climate change and increasing anthropogenic pressure necessitate the production of planting material with enhanced viability and adaptive potential. The quality of planting stock – particularly its morphometric parameters (height, root collar diameter, and root system development) – directly correlates with plant survival after outplanting and subsequent growth performance during the initial years. Therefore, optimization of cultivation technologies aimed at intensifying early growth stages is a critical task for ensuring successful afforestation and forest regeneration in the region.

One of the most effective silvicultural practices for significantly increasing seedling growth vigor and quality is the application of biologically active substances in combination with optimized sowing dates. The use of plant growth regulators stimulates physiological processes in germinating seeds, promoting enhanced cell division, improved root system formation, and accumulation of photosynthetic pigments. Investigating the efficacy of various formulations designed to intensify metabolism and increase resistance to stress factors is of particular relevance. Depending on their chemical nature and mechanism of action, growth regulators may exert differential effects on individual morphological parameters of maple seedlings, necessitating careful classification and analysis to identify the most effective treatments.

Sowing time is a key factor determining seed stratification conditions, the duration of the growing season, and consequently the quality of seedlings at the end of the growing period. Untimely sowing may result in uneven germination, reduced field emergence, or premature termination of vegetation, negatively affecting seedling height and diameter. The importance of this factor is further amplified under the conditions of the Forest-Steppe zone, where temperature regimes and soil moisture in spring and autumn are highly variable.

Seed germination capacity is one of the fundamental indicators of sowing quality and determines the potential stand density of future plantations. In forestry practice, two principal parameters are distinguished: laboratory germination and soil (field) germination. Although laboratory germination is a standardized indicator reflecting the biological viability of seeds under optimal controlled conditions (stable temperature and moisture, absence of pathogens), it does not fully represent germination success under natural nursery conditions.

Soil, or field, germination is a considerably more informative and practically significant indicator, as it reflects the ability of seeds to germinate and produce viable seedlings under conditions closely approximating real-world environments. Unlike laboratory testing, where adverse factors are eliminated, field conditions involve the combined influence of limiting factors such as heterogeneous soil temperature regimes, fluctuations in water balance, the presence of soil-borne pathogens, and competition from weeds.

The discrepancy between laboratory and field germination – often referred to as "field emergence" – is a critical consideration in planning silvicultural operations. As a rule, field germination is consistently lower than laboratory values, and this difference reflects both the sensitivity of seeds to external stressors and the extent to which sowing technology (depth, timing, soil preparation) aligns with the biological requirements of a given tree species. Identifying and minimizing this discrepancy, particularly through optimization of sowing dates and the application of growth regulators, constitutes an important research direction for producing high-quality and competitive planting material such as Norway maple. Thus, field germination serves as an objective criterion for both economic evaluation and technological improvement of seedling production processes.

The conducted studies made it possible to determine the specific patterns of field germination formation in Norway maple seeds depending on sowing date and sowing depth. Analysis of the data obtained for 2025 (Fig. 1) indicates that both factors had a significant effect on germination rates. Overall, the highest germination was recorded for October sowing, averaging 49.1 % (depending on depth), whereas September and November sowing resulted in germination rates of 40.8 % and 32.8 %, respectively. These findings confirm that autumn sowing periods are more optimal, as they ensure natural seed stratification under soil conditions during the autumn–winter period, which is essential for breaking seed dormancy in maple.

October sowing provided the maximum field germination. The highest value observed in the experiment – 52.9 % – was obtained at a sowing depth of 1 cm. This can be explained by the optimal combination of soil temperature and moisture, which creates favorable conditions for the initial stages of stratification while minimizing the risk of seed desiccation. Under the same sowing period, increasing the depth to 2 cm resulted in a 7.6 % decrease in germination (an absolute decline from 52.9 % to 45.3 %), likely due to reduced aeration and increased energy expenditure of the germinating seedling required to penetrate a thicker soil layer.

In the case of September sowing, which is relatively early for the autumn period, the average germination was lower compared to October. At a depth of 1 cm, germination reached 43.9 %, whereas increasing the depth to 2 cm reduced it to 37.7 %. The decrease of 6.2 % in this treatment was less pronounced than in October. This suggests that excessively early sowing may not fully utilize the benefits of natural stratification due to relatively high temperatures during the initial period; however, a clear trend of reduced germination with increased sowing depth remains evident.

The lowest field germination rates were recorded for November sowing, likely due to the onset of stable low temperatures and subsequent soil freezing shortly after sowing, which interrupts or complicates the initial phases of stratification and may cause mechanical damage to seeds. Notably, the difference between sowing depths of 1 cm (29.3 %) and 2 cm (36.3 %) was atypical: deeper sowing resulted in a 7.0 % increase in germination compared to shallow sowing. This unusual result may be attributed to improved thermal protection of seeds at greater depth during November, reducing exposure to temperature fluctuations and preventing desiccation at the soil surface under pre-winter conditions, thereby enhancing seed viability relative to less protected treatments. Nevertheless, even the highest germination observed in November (36.3 %) was significantly lower than the lowest value recorded for October sowing (45.3 %).

In general, the results substantiate the feasibility of selecting October as the optimal sowing period for Norway maple seeds at a sowing depth of 1 cm, as this treatment ensured the highest field germination (52.9 %), exceeding the best September treatment by 9.0 % and the best November treatment by 16.6 %. This confirms the high sensitivity of maple seedlings to silvicultural practices and underscores the importance of optimizing agrotechnical parameters

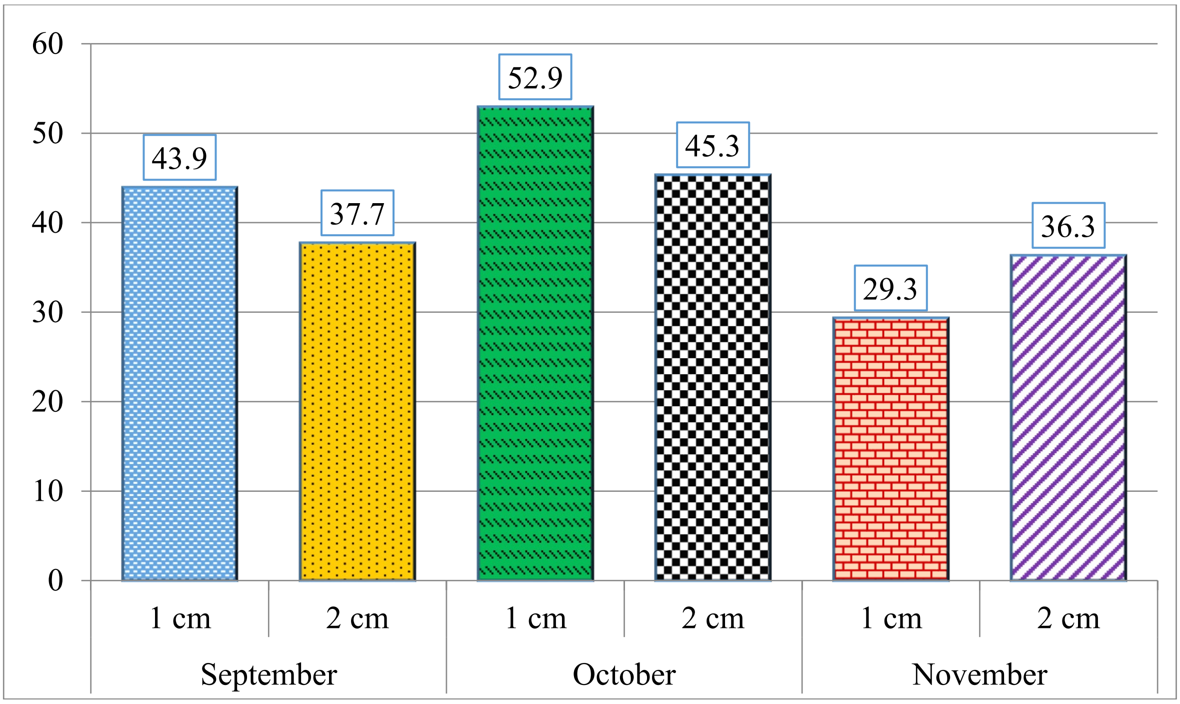


Figure 1. Field germination of Norway maple seeds depending on the sowing date and depth in 2025, %

The assessment of morphometric parameters of one-year-old seedlings constitutes an integral component in the development and improvement of intensive technologies for producing planting material in afforestation. Among all indicators, shoot height and root collar diameter are the most critical criteria for determining seedling standardization and predicting survival after outplanting to a permanent site. It is widely recognized that planting stock meeting established standards for these two parameters exhibits significantly higher viability and more intensive growth rates during the initial years of stand development.

Seedling height directly reflects the vigor of linear growth and the overall assimilative capacity during the growing season. This parameter serves as a direct indicator of the effectiveness of applied silvicultural practices, such as optimization of sowing dates and the use of biologically active substances. The greater the seedling height at the end of the growing season, the more rapidly it can overtop competing herbaceous vegetation and the lower the risk of damage by wildlife. Therefore, analyzing the effects of sowing dates (September, October, and November) and the growth regulator Biosyl on seedling height allows identification of the combinations that most effectively realize the growth potential of Norway maple.

The analysis of one-year-old seedling height in 2025 made it possible to determine the influence of factor A (growth regulators) and factor B (sowing date) on height formation (Table 1). Evaluation of mean values indicates a consistently positive effect of Biosyl application on linear growth compared to the untreated control. On average across all sowing dates, treatment with Biosyl resulted in a seedling height of 34.8 cm, whereas in the control variant this value was only 29.5 cm. This corresponds to an increase of 5.3 cm, or 18.0 %, attributable to the activation of growth processes, thereby confirming the effectiveness of biologically active substances in intensifying planting stock production.

With respect to factor B (sowing date), the highest mean seedling height, irrespective of treatment, was recorded for October sowing (35.1 cm). Slightly lower values were observed for September sowing (32.5 cm), while the lowest mean height (29.0 cm) was characteristic of seedlings sown in November. This trend confirms that October sowing is the most physiologically justified, as it ensures an optimal stratification period and maximum duration of vegetation for biomass accumulation, which is consistent with the previously established maximum seed germination for this sowing period.

A detailed analysis of factor interaction (AB) revealed that the tallest seedlings were obtained under October sowing combined with Biosyl application, where height reached 38.0 cm. This exceeds the corresponding untreated control (32.2 cm) by 5.8 cm. Such a substantial increase indicates a pronounced synergistic effect between optimal germination conditions provided by October sowing and the stimulatory action of the growth regulator.

It should be noted that even under the less favorable September sowing conditions, Biosyl treatment ensured a significant increase in growth: seedling height reached 35.2 cm, which is 5.5 cm higher than the control (29.7 cm). A similar trend was observed for November sowing, where the use of the growth regulator increased seedling height from 26.6 cm (control) to 31.3 cm (Biosyl), demonstrating the capacity of the preparation to partially mitigate the negative effects of late sowing and a shortened growing season.

Thus, the obtained results convincingly demonstrate that, for the production of high-quality Norway maple planting stock, the most effective approach is the combined application of the growth regulator Biosyl with October sowing, which enables the attainment of maximum height in one-year-old seedlings (38.0 cm).

Table 1. Height of Norway maple seedlings as influenced by sowing date and application of growth regulators (2025), cm

Factor A (Growth regulator)	Factor B (Sowing date)	Seedling height, cm	Average for Factor B
Control (Untreated)	September	29.7	32.5
	October	32.2	35.1
	November	26.6	29.0
	Average	**29.5**	
Biosyl	September	35.2	
	October	38.0	
	November	31.3	
	Average	**34.8**	

Root collar diameter, in turn, is an indicator reflecting seedling robustness and the reserve of nutrients (primarily starch and carbohydrates) accumulated in the lower stem and root system. A larger root collar diameter is directly correlated with the strength of mechanical tissues, resistance to lodging, and the ability of seedlings to withstand stress factors (drought, frost) during the critical period following transplantation. Therefore, research results identifying the optimal sowing date and growth regulator application that ensure maximum stem thickening are of decisive importance for developing technological recommendations aimed at producing first-class planting material. Consequently, a detailed quantitative analysis of these two interrelated morphometric parameters is essential for the scientific substantiation of the developed cultivation technology for Norway maple.

The results of studies on the formation of root collar diameter in one-year-old Norway maple seedlings in 2025 (Table 2), analyzed across two factors, demonstrated a pronounced positive effect of both growth regulator application and sowing date optimization on this morphometric trait. On average across all sowing dates, treatment with Biosyl resulted in a root collar diameter of 3.17 mm, which is 0.21 mm greater than in the control ("untreated"), where the mean value was 2.96 mm. The relative increase in diameter attributable to the regulator was 7.1 %, confirming its effectiveness in enhancing secondary growth processes and nutrient accumulation in the root collar zone.

With respect to factor B (sowing date), the highest mean root collar diameter, irrespective of growth regulator application, was observed under October sowing (3.13 mm). This result is fully consistent with the data obtained from the analysis of seedling height and indicates that October sowing provides the most favorable conditions for balanced growth and development of Norway maple seedlings. Slightly lower diameter values (3.03 mm) were recorded for both September and November sowing dates. Although identical in magnitude, these results indicate that both excessively early (September) and delayed (November) sowing limit the duration and intensity of growth processes, leading to a comparable reduction in stem thickening rates.

Analysis of factor interaction (AB) clearly demonstrated that the maximum root collar diameter (3.24 mm) was achieved under the combination of October sowing and Biosyl treatment. This finding indicates a synergistic effect of optimal environmental conditions (October sowing) and physiological stimulation (growth regulator application), which together create the most favorable conditions for intensive seedling thickening.

Moreover, even under September sowing conditions, the application of Biosyl ensured the formation of a diameter of 3.11 mm, which significantly exceeded the corresponding control (2.95 mm). It is also noteworthy that Biosyl application under November sowing resulted in a diameter of 3.15 mm, which is unexpectedly high, as it exceeded the diameter of seedlings treated with Biosyl but sown in September (3.11 mm).

Table 2. Root collar diameter of Norway maple seedlings as influenced by sowing date and application of growth regulators (2025), mm.

Factor A (Growth regulator)	Factor B (Sowing date)	Root collar diameter, mm	Average for Factor B
Control (Untreated)	September	2.95	3.03
	October	3.02	3.13
	November	2.91	3.03
	Average	2.96	
Biosyl	September	3.11	
	October	3.24	
	November	3.15	
	Average	3.17	

This result is likely attributable to the fact that the growth regulator effectively compensates for the shortened autumn growing season and promotes rapid seedling thickening in the spring, allowing for the accumulation of sufficient plastic substances to form a superior stem thickness compared to the September sowing variant. Despite this specific feature, the optimal combination remains the October sowing date in conjunction with Biosyl (3.24 mm).

The length of the main root exhibits a direct correlation with the drought resistance of the seedlings. Greater root length provides the plant with access to moisture and nutrients from deeper soil horizons, particularly under conditions of summer drought, which is indispensable for survival and intensive growth after transplanting [5, 18]. Since Norway maple is an associate species frequently utilized to enhance the stability of forest cultures, the formation of a developed and deep root system is a priority task. An analysis of the influence of sowing dates (September, October, November) and the application of the growth regulator Biosyl on this indicator allows for the identification of optimal agrotechnical solutions that stimulate geotropism and root growth energy.

The results of the study aimed at investigating the influence of Factor A (growth regulators) and Factor B (sowing date) on the formation of the main root length of one-year-old Norway maple seedlings in 2025 (Table 3) are of particular significance, as root system development is a determining factor for drought resistance and overall seedling resilience in permanent forest plantation areas. The analysis of mean values clearly demonstrates that the application of the regulator Biosyl had a pronounced growth-stimulating effect on the root system. On average across all sowing dates, treatment with this growth regulator allowed for the formation of a main root with a length of 24.4 cm, whereas in the control variants ("Untreated"), the average root length was only 18.7 cm. The difference amounts to 5.7 cm, or a 30.5 % advantage in favor of the Biosyl variant, confirming its high efficiency in activating the root's meristematic tissues.

When considering the influence of the sowing date (Factor B) on root length formation, an atypical but important trend is observed: the maximum average root length (23.2 cm) was recorded for the November sowing date, while the lowest indicators were observed for the September and October sowing dates – 20.8 cm and 20.6 cm, respectively. This result is likely explained by the fact that seeds sown in November undergo a more prolonged and intensive influence of low temperatures under conditions of natural stratification, which may promote more thorough post-harvest ripening and, consequently, more active root growth in the spring, while also forming a more resilient root system that enhances the quality of the planting material.

Table 3. Main root length of Norway maple seedlings depending on sowing date and growth regulator application (2025), cm

Factor A (Growth regulator)	Factor B (Sowing date)	Main root length, cm	Average for Factor B
Control (Untreated)	September	18.5	20.8
	October	17.0	20.6
	November	20.5	23.2
	Average	**18.7**	
Biosyl	September	23.1	
	October	24.2	
	November	25.9	
	Average	**24.4**	

A detailed analysis of the factor interaction (AB) allows for the identification of the optimal variant, which ensured the absolute maximum main root length of 25.9 cm. This indicator was obtained through the combination of the November sowing date and seed treatment with Biosyl. Compared to the control (untreated) in November (20.5 cm), the increment due to Biosyl was 5.4 cm. Simultaneously, Biosyl treatment during the October sowing date ensured a root length of 24.2 cm, which nearly corresponds to the maximum value and represents the most intensive increment compared to the October control (17.0 cm) – a difference of 7.2 cm, or an impressive 42.4 %. This indicates that while the October sowing in control variants forms the weakest root, the use of the regulator compensates for this deficiency to the greatest extent. Even for the September sowing date, Biosyl treatment increased the root length to 23.1 cm, compared to only 18.5 cm in the control. It was established that in all cases, the application of Biosyl increases root length; however, the November sowing date in combination with the growth regulator ensured the absolute maximum (25.9 cm), which is critical for ensuring the high quality of Norway maple planting material.

The ratio of aboveground to belowground phytomass is an integral indicator of seedling architectonics and one of the most objective criteria of its structural balance. In forest physiology and nursery practice, seedlings with lower values of this ratio (i.e., those possessing a relatively greater root mass compared to the shoot) are considered to be of higher quality and greater stability. Such a balance ensures improved physiological readiness to withstand transplant shock and increases the likelihood of successful establishment, as it minimizes the imbalance between a large transpiring surface (foliage) and an insufficient water-supplying system (roots) following lifting. Studies aimed at the targeted reduction of this ratio through the application of growth regulators demonstrate the possibility of managing physiological processes to obtain planting stock with enhanced ecological tolerance. Therefore, a detailed analysis of the effects of the studied factors on this parameter enables the development of a scientifically substantiated cultivation technology that ensures not only high-quality but also adaptive Norway maple planting material.

The results of studies on the aboveground-to-belowground phytomass ratio in one-year-old Norway maple seedlings for 2025 (Table 4) are of considerable ecological and practical importance, as this coefficient serves as an objective indicator of planting stock quality and adaptive potential. In afforestation practice, seedlings with lower values of this ratio are considered more resistant to adverse environmental conditions (particularly drought), as they possess a relatively better-developed root system.

Analysis of mean data clearly indicates that the application of the growth regulator Biosyl had a pronounced positive effect on this parameter by promoting its reduction. On average across all sowing dates, Biosyl treatment resulted in a ratio of 1.3, whereas in the untreated control this value was 1.8. The reduction of the ratio by 0.5 (or 27.8 %) confirms that Biosyl stimulated preferential root system development, which aligns with the requirements for high-quality planting material.

With respect to factor B (sowing date), the lowest mean ratio, irrespective of treatment, was recorded under November sowing (1.4), indicating the greatest relative advantage in root development for this variant. Higher values (1.6), reflecting a somewhat greater proportion of aboveground biomass, were characteristic of both September and October sowing. This pattern is consistent with root length data, where November sowing demonstrated a tendency toward enhanced belowground development, whereas September and October sowing – despite producing taller seedlings – resulted in a more balanced but less desirable biomass allocation.

A detailed analysis of factor interaction (AB) made it possible to identify the variant that ensured the most favorable (minimum) ratio of 1.1. This value was obtained under the combination of November sowing and Biosyl treatment. Compared with the untreated November control (1.7), the difference amounted to 0.6, or approximately 35.3 %, representing the greatest improvement among all experimental variants. This indicates a strong synergistic effect between physiological stimulation induced by Biosyl and the biological processes associated with late autumn sowing, resulting in planting material with an optimal root–shoot balance.

Even under October sowing conditions, Biosyl treatment ensured a low ratio of 1.3, which is substantially better than the corresponding control (1.9). Similarly, under September sowing, the ratio was 1.4 with Biosyl compared to 1.8 in the control. Across all treatments involving Biosyl, the ratio remained below 1.4, whereas in control variants it ranged between 1.7 and 1.9. This confirms that the application of Biosyl is the most effective silvicultural practice for deliberately shifting biomass allocation toward root system development in Norway maple seedlings.

Table 4. Aboveground-to-belowground phytomass ratio in Norway maple seedlings as influenced by sowing date and application of growth regulators (2025).

Factor A (Growth regulator)	Factor B (Sowing date)	Shoot-to-root ratio	Average for Factor B
Control (Untreated)	September	1.8	1.6
	October	1.9	1.6
	November	1.7	1.4
	Average	**1.8**	
Biosyl	September	1.4	
	October	1.3	
	November	1.1	
	Average	**1.3**	

The results of the analysis of variance (ANOVA), reflecting the influence share of the studied factors (growth regulator treatment and sowing dates) on the shoot-to-root ratio of one-year-old Norway maple seedlings, are essential for an objective assessment of the significance of each agrotechnical method and for identifying the primary regulators of this critical quality indicator. The shoot-to-root ratio serves as an integral quality criterion that determines the adaptive potential of seedlings, where a lower coefficient value indicates superior resilience to adverse environmental conditions.

It was established that Factor A (growth regulator) exerts the determining influence on the formation of the shoot-to-root ratio. Its share in the total variability of the indicator reached 86 %. This confirms that bioactive substances, specifically the regulator Biosyl, act as the primary tool capable of purposefully altering seedling architectonics by redistributing growth energy in favor of the root system (as previously demonstrated by the reduction of the coefficient to 1.1), which is of paramount importance for producing high-quality planting material. This result underscores the high efficiency of chemical stimulation over temporal (seasonal) parameters.

Factor B (Sowing date), although possessing a significantly smaller influence share, remains statistically significant, accounting for 11 % of the total variation. This influence is attributed to the varying duration of natural stratification and the growing season conditions provided by sowing in September, October, and November. Despite the dominant role of the growth regulator, the optimization of sowing dates remains important for the fine-tuning of biological processes and the formation of the desired ratio.

It is also noteworthy that the Interaction AB (Biosyl × Sowing date) demonstrates the smallest yet still significant influence share, amounting to 3 %. This indicator suggests that while synergistic effects exist (as shown by the November sowing + Biosyl yielding the optimal result of 1.1), they are not the primary source of variation. The core variability of the indicator, totaling 86 %, is unequivocally linked to the action of the Biosyl preparation itself, rendering it the priority agrotechnical measure in the cultivation technology of Norway maple.

Thus, the results of the analysis of variance scientifically substantiate that the primary factor determining the balanced development of Norway maple seedlings and their potential resilience is the application of a growth regulator, which should form the basis of recommendations for the intensification of planting material cultivation.

Conclusions. Established that the October sowing date is optimal for achieving high field germination of Norway maple seeds. The maximum germination rate of 52.9 % was recorded for October sowing at a depth of 1 cm. This value is 9.0 % higher compared to the best September sowing variant and 16.6 % higher than the best November variant, confirming the significance of sowing depth and timing for natural stratification.

Revealed a positive effect of treating seedlings with the growth regulator Biosyl on the morphometric indicators of one-year-old Norway maple seedlings. On average across all sowing dates, the application of Biosyl ensured an increase in seedling height by 18.0 % (to 34.8 cm versus 29.5 cm in the control) and an increase in root collar diameter by 7.1 % (to 3.17 mm versus 2.96 mm in the control).

Determined a synergistic effect of factor interaction that ensured the formation of the tallest seedlings. Maximum height (38.0 cm) and root collar diameter (3.24 mm) were achieved with the October sowing date combined with the application of the growth regulator Biosyl, indicating this variant as the most effective for achieving standard parameters of the above-ground part.

Ascertained that the maximum main root length of one-year-old seedlings (25.9 cm) was ensured by the combination of the November sowing date and seedling treatment with Biosyl. In this variant, the increment due to the regulator was 5.4 cm compared to the control. However, the highest relative increment in root length (42.4 %, or 7.2 cm) was recorded for the October sowing date following Biosyl treatment (24.2 cm versus 17.0 cm in the control).

Established that the application of Biosyl leads to a shift in the biomass balance in favor of the root system, which is a desirable trait for increasing the adaptability of planting material. The most favorable minimum shoot-to-root ratio of 1.1 was obtained with the November sowing date combined with Biosyl treatment. This is 35.3 % lower compared to the corresponding control (1.7), confirming that Biosyl effectively stimulates the preferential development of the underground part, which is critical for drought resistance.

Proven that the application of the growth regulator Biosyl is the primary factor determining seedling balance. This factor accounts for 86 % of the influence on the variability of the shoot-to-root ratio. Due to the action of Biosyl, the most desirable coefficient (1.1) was obtained during the November sowing date, which is 35.3 % lower than the control and indicates a purposeful shift of the biomass balance in favor of the root system.

Recommended that to ensure the maximum yield of standard Norway maple planting material characterized by an optimal balance of above-ground and underground parts, the integrated application of seedling treatment with the growth regulator Biosyl is most expedient. Furthermore, the October sowing date is optimal for maximizing height and diameter, while the November sowing date is optimal for ensuring maximum root system development and a superior biomass ratio.

Recommendations. Under the conditions of the Krasnopillia forestry enterprise, to increase the field germination rate and obtain high-quality Norway maple planting material, it is recommended:

- To perform seed sowing in October at a depth of 1 cm;
- To form planting material with the most developed root system, it is advisable to treat seedlings with the growth regulator "Biosyl" during the spring period at a dosage of 20 ml/ha with a working solution consumption of 300 l/ha.

REFERENCES

1. Assmuth A., Rämö J., Tahvonen O., (2021) Optimal carbon storage in mixed-species size-structured forests. *Environmental and Resource Economics*, Vol.79, N.2, P.249–275.
2. Belelya S., (2015) Effect of plant growth regulators on the growth of Larix kaempferi seedlings. Scientific Bulletin of UNFU, Vol.25, N.1, P.36–44.
3. Bianchi E., Bugmann H., Bigler C., (2019) Early emergence increases survival of tree seedlings in Central European temperate forests despite severe late frost. *Ecology and Evolution*, Vol.9, N.14, P.8238–8252. https://doi.org/10.1002/ece3.5399
4. Chivulescu S., Cadar N., Hapa M., Capalb F., Radu R., Badea O., (2023) The necessity of maintaining the resilience of Peri-urban forests to secure environmental and ecological balance. *Diversity,* Vol.15, N.3, P.380. https://doi.org/10.3390/d15030380
5. Debryniuk I., Myklush Ya., (2021) Influence of Betula pendula Roth. on taxation indicators of Pinus sylvestris L. in forest cultures of fresh pine forest of Western Polissia. *Proceedings of the Forestry Academy of Sciences of Ukraine,* N.23, P.79–90.
6. Draghici C., Abrudan I., (2011) The effect of different stratification methods on the germination of *Acer platanoides* and *Acer campestre* seeds. *Bulletin of the Transilvania University of Brasov,* Vol.4, P.29–34.
7. Fang W., Wang X., (2020) A field experimental study on the impact of *Acer platanoides*, an urban tree invader, on forest ecosystem processes in North America. *Ecological Processes*, Vol.9, N.1, P.9.
8. Giberti G., Wellstein C., Giovannelli A., Bielak K., Uhl E., Aguirre-Ráquira W., Tonon G., (2022) Annual carbon sequestration patterns in trees: A case study from scots pine monospecific stands and mixed stands. *Forests,* Vol.13, N.4, P.582. https://doi.org/10.3390/f13040582
9. Gómez-Aparicio L., Canham C., Martin P., (2008) Neighbourhood models of the effects of the invasive *Acer platanoides* on tree seedling dynamics. *Journal of Ecology*, Vol.96, N.1, P.78–90.
10. Gurau L., Petru A., (2018) The influence of CO2 laser beam power output and scanning speed on surface quality of Norway maple (*Acer platanoides*). *BioResources,* Vol.13, N.4, P.8168–8183.
11. Havryliuk V., Huz M., Kharachko T., Yaroshchuk R., (2013) Growing European larch seedlings using growth stimulants and different methods of seed stratification. *Bulletin of Sumy National Agrarian University. Series: Agronomy and Biology,* N.11, P.3–7.
12. Hawkins B., Jones M., Kranabetter J., (2015) Ectomycorrhizae and tree seedling nitrogen nutrition in forest restoration. *New Forests*, Vol.46, N.5, P.747–771.
13. He Y., Zhang Q., Jiang C., Lan Y., Zhang H., Ye S., (2023) Mixed planting improves soil aggregate stability and aggregate-associated CNP accumulation in subtropical China. *Frontiers in Forests and Global Change*, Vol.6, P.1141953. https://doi.org/10.3389/ffgc.2023.1141953
14. Hilmers T., Mehtätalo L., Bielak K., Brazaitis G., del Río M., Ruiz-Peinado R., Pretzsch H., (2025) Towards resource-efficient forests: Mixing species changes crown biomass allocation and improves growth efficiency. *Plants, People, Planet*, Vol.7, N.1, P.117–132.
15. Karpenko V., (2013) Silvicultural properties of associated species in oak stands of the Forest-Steppe of Ukraine. *Scientific Bulletin of NUBiP of Ukraine. Series: Forestry and Decorative Horticulture,* Vol.187, N.1, P.248–253.
16. Kimeichuk I., Khryk V., Levandovska S., Tretiak A., Kucheriavenko O., (2022) Afforestation – the main method of eco-adaptive forest reproduction and increasing forest cover of Ukraine. *Theoretical foundations in research in Engineering,* P.20–41. https://doi.org/10.46299/ISG.2022.MONO.TECH.3
17. Koelzer K., Ribarits A., Weyermair K., Bouchal J., Mayr J., Weber M., (2024) Trees Are a Major Foraging Resource for Honeybees in the City. *Plants*, Vol.13, N.21, P.3094. https://doi.org/10.3390/plants13213094.
18. Konovaliuk S., (2022) Altitudinal distribution of vegetation of the Ukrainian Carpathians and ecological groups of dominant species of formed phytocoenoses. *Modern Problems of Ecology*, P.32.
19. Kratiuk O., (2019) Silvicultural and taxation characteristics of stands in enclosures of Central Polissia. *Scientific Bulletin of UNFU*, Vol.29, N.3, P.36–38. https://doi.org/10.15421/40290307
20. Kunakh O., Zhukov O., (2025) The Norway maple (*Acer platanoides*) population space location and vital state in the urban park. *Agrology,* Vol.8, N.1, P.25–33. https://doi.org/10.32819/202504
21. Kyryliuk V., Borovyk P., (2021) Irrigation of a forest nursery. *Modern technologies and achievements of engineering sciences in the field of hydraulic engineering and water engineering*, Vol.3, P.107
22. Lenevych O., Leleka D., (2024) Morphological features of forest litter of old-growth forests in protected areas of the Western regions of Ukraine. *Scientific Bulletin of UNFU, Vol.34, N.8, P.88–95*. https://doi.org/10.36930/40340810
23. Leslie A., Short I., (2025) Mixed species broadleaved and broadleaved/conifer stands in Great Britain for timber production. *Quarterly Journal of Forestry*, Vol.119, N.2, P.82–88.
24. Luo Y., He J., Long Y., Xu L., Zhang L., Tang Z., Xiong X., (2023) The relationship between the color landscape characteristics of autumn plant communities and public aesthetics in urban parks. *Sustainability,* Vol.15, N.4, P.3119. https://doi.org/10.3390/su15043119
25. Mania P., Siuda F., Roszyk E., (2020) Effect of slope grain on mechanical properties of different wood species. *Materials,* Vol.13, N.7, P.1503. https://doi.org/10.3390/ma13071503

26. Matkovska S., Svitylskyi M., Ischuk O., Pinkina T., Fediuchka M., Solomatina V., (2019) Ecological role of representatives of the genus *Acer* L. in green spaces of Zhytomyr city. *Scientific Bulletin of UNFU*, Vol.29, N.1, P.70–73.
27. Moskałyk G., Leheta U., (2019) Allelopathic properties of species of the genus *Acer* L. *Scientific Bulletin of Chernivtsi University. Biology (Biological Systems)*, Vol.11, N.2, P.154–160
28. Oleksiichenko N., Manko M., (2012) Species and form diversity of plants of the genus *Acer* L. in Ukraine and greening of Kyiv city. *Scientific Bulletin of NUBiP of Ukraine. Series: Forestry and Decorative Horticulture*, N.171, P.253–259.
29. Oravec A., Ferus P., Košútová D., Konôpková J., (2023) Screening for drought resistance among ornamental maples (*Acer* sp.). A field experiment in juvenile plants. *Dendrobiology,* Vol.89, P.35–45. https://doi.org/10.12657/denbio.089.004
30. Osmachko O., Bakumenko O., Melnyk T., Melnyk A., Kriuchko L., (2024) Development of an organizational and economic plan for the creation of a permanent decorative nursery in the conditions of the branch "Lebedyn Forestry". *Bulletin of Uman National University of Horticulture,* N.1, P.45–52. https://doi.org/10.32782/2310-0478-2024-1-45-52
31. Pavlishchuk O., Rozvod S., (2012) Theoretical and methodological foundations of economic evaluation of the carbon deposition function of forests based on the rent approach. *Scientific Bulletin of UNFU*, Vol.22, N.9, P.30–37.
32. Prakash I., (2024) Comprehensive Review of Maple Trees: Evolution, Biogeographical Distribution, Ecology, and Economic Significance. *Indian Journal of Ecology*, Vol.15, P.1418–1423. https://doi.org/10.55362/IJE/2024/4418
33. Psistaki K., Tsantopoulos G., Paschalidou A., (2024) An overview of the role of forests in climate change mitigation. *Sustainability*, Vol.16, N.14, P.6089. https://doi.org/10.3390/su16146089
34. Quoreshi A., Khasa D., (2008) Effectiveness of mycorrhizal inoculation in the nursery on root colonization, growth, and nutrient uptake of aspen and balsam poplar. *Biomass and Bioenergy*, Vol.32, N.5, P.381–391.
35. Razanova A., (2025) Nectar-pollen woody species of shelterbelts of the Right-Bank Forest-Steppe and their role in modern beekeeping. *Beekeeping of Ukraine,* N.14, P.88–94. https://doi.org/10.32782/beekeepingjournal.2025.14.12
36. Rizwan M., Gilani S., Durrani A., Naseem S., (2022) Kinetic model studies of controlled nutrient release and swelling behavior of combo hydrogel using *Acer platanoides* cellulose. *Journal of the Taiwan Institute of Chemical Engineers*, Vol.131, P.104137. https://doi.org/10.1016/j.jtice.2021.11.004
37. Seiwa K., (2007) Trade-offs between seedling growth and survival in deciduous broadleaved trees in a temperate forest. *Annals of Botany*, Vol.99, N.3, P.537–544.
38. Singh S., Tripathi D., Tripathi S., (2025) The role of forest ecosystems for carbon capture and storage in India. International Journal of Agriculture and Environmental Research**,** Vol.11, N.5, P.1719–1749. https://doi.org/10.22004/ag.econ.376239
39. Staszak A., Guzicka M., Pawłowski T., (2017) Signalling regulators of abscisic and gibberellic acid pathways are involved in dormancy breaking of Norway maple seeds. *Acta Physiologiae Plantarum,* Vol.39, N.11, P.251.
40. Syniavskyi Yu., Huz M., Baranov V., Tehlivets S., Karpinets L., (2016) Influence of growth regulators on sowing quality of seeds and biochemical parameters of Metasequoia glyptostroboides seedlings. *Bulletin of Lviv University. Biological Series,* N.74, P.201–208.
41. Talal M., Santelmann M., Tilt J., (2021) Urban park visitor preferences for vegetation–An on-site qualitative research study. *Plants, People, Planet*, Vol.3, N.4, P.375–388. https://doi.org/10.1002/ppp3.10188
42. Telekalo N., Matusyak M., Prokopchuk V., (2021) Silvicultural and ecological features of reforestation and afforestation in Podillia. Monograph, P.184
43. Turturika M., (2023) Features of morphogenesis of *Acer platanoides* Globosum on a trunk under different options of growing *Acer platanoides* L. rootstock. *Theoretical aspects of education development*, P.22.
44. Udda Ya., Bilchuk V., Khmelnykova L., (2019) Features of the state of seeds of different species of the genus *Acer* L. under the condition of technogenic pollution. *Scientific Spring*–2019, N.10, P.100–101.
45. Vdovenko S., Matusyak M., Pantsyreva G., (2023) Peculiarities of growing European larch planting material by intensive methods in the conditions of the VNAU biostation. *Balanced Nature Management,* N.3, P.115–120. https://doi.org/10.33730/2310-4678.3.2023.287825
46. Wangen S., Webster C., (2006) Potential for multiple lag phases during biotic invasions: reconstructing an invasion of the exotic tree *Acer platanoides*. *Journal of Applied Ecology,* Vol.43, N.2, P.258–268. https://doi.org/10.1111/j.1365-2664.2006.01138.x
47. Wiseman P., Wells C., (2009) Arbuscular mycorrhizal inoculation affects root development of *Acer* and Magnolia species. *Journal of Environmental Horticulture, Vol.27, N.2, P.70–79.*
48. Zaitseva I., Povorotnya M., (2015) Quantitative assessment of the influence of hydrothermal factors on the water exchange of woody plants of the genus *Acer* L. in the conditions of the Steppe zone. *Ecology and Noospherology*, Vol.26, N.1-2, P.25–33.
49. Zhang X., Ma Y., Fu S., Qian J., Zhu Q., Feng C., Chen H., (2024) Effect and mechanisms of conifer and broadleaf mixtures on the soil characteristics in limestone mountains. *Turkish Journal of Agriculture and Forestry*, Vol.48, N.2, P.199–211. https://doi.org/10.55730/1300-011X.3174
50. Zhemchugova E., Voitovych O., (2024) Variability of *Acer negundo* seeds as a factor of ecological plasticity of the species. *Universum,* N.15, P.247–25

AGROTECHNOLOGICAL PRINCIPLES OF PRODUCTION OF PLANTING MATERIAL *SALIX MATSUDANA L.* AND THE FEATURES OF ITS USE IN THE IMPROVEMENT OF RECREATIONAL FACILITIES

Tokman Volodymyr
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0002-1237-4611

The environmental strategy of cities and other settlements is aimed at developing and preserving the city's plant fund, for this purpose a system of monitoring the condition of green spaces is used. It requires a set of measures that ensure appropriate control, development of measures for the restoration and protection of territories, forecasting the condition of perennial plantings, taking into account environmental conditions and other factors that determine their condition and level of improvement [8, 10, 12, 14, 16]. At the same time, the main components of the monitoring system for the condition of perennial plantings are: - assessment of quantitative and qualitative indicators of the condition of plants in the territory; - identification and establishment of the main causes of the deterioration of the condition of plantings; - development of a comprehensive program of measures aimed at eliminating the consequences of the impact of negative factors on perennial plantings and eliminating the factors themselves; - modeling the development of the situation.

Relevance. Today, there is a need to create perennial plantings near lakes and reservoirs, which are located both in the surrounding areas and within the boundaries of the settlement. In connection with the above, there is a need to search for fast-growing taxa and their decorative forms that have high decorative characteristics. From this list, the most promising are *Salix* species and hybrids, which can be widely introduced into the improvement of urban areas [16]. Therefore, an important element in landscaping settlements where there are or are planned to create reservoirs is the use of *Salix* cultivars, and in particular *Salix matsudana* L. These taxa must meet two main requirements: growth rate and decorativeness. Therefore, the issue of using *Salix* in landscape design is relevant.

Purpose and objectives of the research. Scientific and practical justification of the possibility of producing planting material *S. matsudana* for the improvement of recreational facilities.

To achieve the set goal, the following tasks were performed:

- to analyze the taxonomic composition of representatives of the genus *Salix* L.;
- to study the influence of the thickness of the cutting material on the biometric indicators of *S. matsudana* plants;
- to consider the influence of growing conditions on the growth and development of *S. matsudana* plants;
- to provide suggestions for the use of *S. matsudana* for the creation of recreational facilities.

The object of the research is *S. matsudana*.

The subject of the research is the botanical and biological properties of *S. matsudana*.

The genus *Salix* is the most numerous among the family *Salicaceae.* Its representa-

tives are found in various climatic zones - from deserts to tundra. Approximately 30 taxa of the mentioned genus grow in Ukraine, a number of cultivars are used in landscaping. *Salix* in the alpine, subalpine belt of mountains, forest-tundra and tundra, play a corresponding role, sometimes the main role in the creation of plant stands [4, 21]. In the forest zone, they are temporary, inhabiting burned and cut-down areas, later replaced by long-lived species. In the deserts and steppe zone, they grow in lowlands and floodplains of rivers.

Figure 1. Salix caprea L.

S. caprea (Fig. 1) is a tall shrub or tree up to 20 m in height. The bark is smooth, gray-green. The wood under the bark has a reddish tint. Mature shoots are bare, thick. The buds are brown in color, large. The leaf blade is ovate or elliptical, 12-17 cm long, the edges are serrated, the veins are clearly defined, the underside is pubescent, there are stipules that fall off early [20].

The catkins are thick, large; the female catkins are green, oblong, and the male catkins are yellow. Flowering occurs before the leaves bloom, in March - April.

The fruits ripen during May - June and are collected in axils. The species belongs to fast-growing, frost-resistant and shade-tolerant species. It is a fairly common species in Ukraine [24, 26, 30].

Today, various decorative forms of *S. caprea* are used in landscape design: Kilmarnock (Fig. 2), Bredina (Fig. 3), Pendula (Fig. 4) and others.

Figure. 2. S. caprea Kilmarnock

Kilmarnock (Fig. 2) is a deciduous, ornamental tree grafted onto a stock with an umbrella-shaped or weeping crown, shoots hanging down. The height of the plant depends on the level of grafting, mainly 1.2-2 m, the width is 1.0-2 m. The tree after grafting grows to a height of no more than 20 cm. The branches of *Salix* Kilmarnock rise up to 40 cm and hang down. With regular pruning, the crown acquires a decorative appearance: lush, beautiful, umbrella-shaped. The leaf surface is wrinkled, oblong-elliptical, dull green, grayish on the underside, with stipules, autumn color is yellow. Flowering occurs in March - April, before the buds swell, the bare branches are covered with fluffy, soft, yellow-golden catkins, with a pleasant aroma. Spectacular decorative catkins delight the owner from early spring until the leaves appear. The bark on the shoots is gray-green, and gray with age. The root system is located in the upper soil layer (up to 0.45 m).

Kilmarnock is an undemanding plant, but it needs a lot of water and light for its development. It can grow on various soils, but prefers light loamy soils, from slightly alkaline to slightly acidic, on light soils it may shed its leaves, it is advisable to avoid high lime content.

Salix on a trunk is a beautiful plant for the garden. Trunk plants have been used for quite a long time. These plants mark the entrance to the porch or the house. They are used for mixed compositions and garden plots. They look attractive in alley plantings and topiary gardens.

Kilmarnock is suitable for landscaping gardens and parks in single and group plantings, near water bodies, as a single plant, or even planted in a container.

Frost resistance zone: 4. It is wind-resistant, sensitive to late frosts.

Figure 3. S. caprea Bredina

Bredina is a tree that has a highly decorative crown (Fig. 3). It forms long, thin, hanging branches. The crown thickness reaches 170 cm. The plant is demanding on moisture, feels good along roads and on forest edges. The mentioned decorative form lives up to 35 years. The leaf blade is oval, smooth, with a pointed tip. The flowers are yellow. The length of the catkins, which have decorative beauty, is 30-40 mm.

The decorative form is not picky about the soil environment, tolerates autumn frosts and low temperatures in the winter period. It is quite photophilous, but can grow in conditions of relative light deficiency.

It is used in single and mixed compositions.

Figure 4. S. caprea Pendula

Pendula is a highly ornamental tree (Fig. 4). It is widespread in Central Asia and Eastern Europe. The ornamental form is used in landscaping, it has a weeping, rounded crown and a flat central conductor.

In addition, it is characterized by rapid growth, reaching 50-100 mm, and the growth of the crown is 200 mm, and therefore constant removal of excess branches is performed to form the shape. The leaves are olive-green in summer, and in autumn they acquire a golden color. The named representative is winter- and frost-resistant, but it is desirable to insulate it. *Salix* is watered periodically, but the water should not stagnate. At the same time, in the summer period it is necessary to spray the crown. An important role is played by the application of mineral fertilizers during the growing season. Seedlings are planted in a fertile substrate of optimal acidity, which is well aerated. Pendula is combined with various types of coniferous and decorative deciduous species, where it is the main component, and has an attractive decorative appearance.

Figure 5. S. cinerea L.

S. cinerea is a plant up to 7 m tall (Fig. 5). The wood does not turn red under the bark. The stems are covered with gray hairs. The leaf blade is ovate, up to 13 cm long, wrinkled, the edges are serrate, the stipules are toothed. The flowers are dioecious. Flowering occurs before or simultaneously with the swelling and opening of the buds. The fruits ripen in the third decade of May - the first decade of June. The taxon is winter- and frost-resistant, shade-tolerant, undemanding to the soil environment. The cultivar is widespread in Kazakhstan, Southern Europe, Central Asia and Siberia.

Plants of the mentioned taxon are planted near water bodies – they grow and develop well in conditions of sufficient moisture supply. Gardeners and landscape design specialists use the named species to form hedges. The taxon fits perfectly into the composition of a park or a square. The bush will look perfect in combination with deciduous species that have a golden color. Some specialists plant *Salix* in oriental-style gardens.

The cultivar is undemanding to the soil environment, but light loamy soils are best for it. *S. cinerea* will develop well in conditions of close groundwater.

For planting planting material, it is advisable to prepare a planting pit measuring 60*60 cm. The pit is filled one third with a substrate, which includes compost, field soil and peat (1:1:1). When planting, mineral fertilizers are applied. When planting *Salix* to form a hedge or alley, a trench is dug 45 - 60 cm wide and 50 cm deep.

It is advisable to buy planting material with an undamaged root system. A seedling with a closed root system is planted at any time of the year - from March to November. Seedlings with a bare root system are planted before the buds swell.

After planting, *Salix* requires watering - from 15 to 25 liters of water once every 10 days. In hot weather, water the plant once every seven days.

Pruning of bushes is carried out once or twice during the growing season. The first pruning is advisable to carry out in spring, and the next - in July.

The plant responds well to fertilizing with complex fertilizers. Fertilizers are used two to three times, starting in spring and ending at the end of July.

Young plants require shelter for the winter season. In addition, it is best to plant *Salix* in areas that are protected from drafts and winds - otherwise the planting material will freeze in winter.

Figure 6. S. cinerea Tricolor

Tricolor is a standard tree with a dense rounded crown and raised, very thin, flexible, numerous shoots (Fig. 6). The height of the tree is 2.5-3 m, the diameter of the crown is 2.5-3 m. The leaves are bluish-green, silky with strokes and spots of cream, and in spring a pinkish-cream shade. The flowers are oblong. The catkins are colored in yellow, cream and red. It blooms in the third decade of April, simultaneously with the swelling of the buds. The decorative form is undemanding to the soil environment, grows on relatively moist and dry soils, from slightly alkaline to slightly acidic. The decorative form is photophilous, withstands conditions of relative light deficiency. In the hot period, it requires a sufficient amount of moisture, is wind-resistant, and does not tolerate transplanting well. It requires shaping pruning. It is used in solitary and group plantings, for creating compositions, and decorating reservoirs.

Figure 7. Salix alba

S. alba is a dioecious plant belonging to the *Salicaceae* family (Fig. 7). The tree is up to 27 m high and up to 2.5 m thick. The crown is round, wide. The bark is cracked, gray. Young shoots of *Salix* have fluffy-silvery tips, and branches are brown, bare. Buds are red-yellow, sharp, pressed to the stem. Leaves are up to 13 cm long, lanceolate, edges are finely serrate, apex pointed, silvery-villous, stipules fall off. Young leaves are drooping, have a white-silvery hue, adult leaves are white-silvery above. The leaf blade is pubescent along the central vein below, and glabrous above. The flowers of *S. alba* are unisexual, collected in catkins. Male flowers are cylindrical, yellow, 6-8 cm long and up to 10 mm wide, female flowers are thin, greenish. Bract scales are pale in color. Fruit is a capsule, trees bloom during April - May after the formation of leaves. The culture is long-lived (90-120 years), light-loving, frost- and winter-hardy. It is distributed in Central Europe, Central Asia, Siberia, and the Caucasus.

The mentioned species is a forest-forming species in river floodplains. It often forms pure, highly productive stands. It grows along the banks of reservoirs, in wet meadows.

The taxon is one of the early and valuable honey plants. Bees take nectar, bee glue and pollen from Salix plantations. Bees make up to 3-4 kg of honey per day (150 kg from 1 ha) from nectar. Willow honey is golden yellow in color, when crystallized it becomes fine-grained, acquires a creamy shade, and has good taste.

S. alba is a light-loving plant. The plant requires regular, abundant watering. It is undemanding to the soil environment, but grows better on well-aerated, moist and fertile soils [5]

It is used in the landscaping of parks, for creating alleys on the banks of reservoirs and forming recreational areas. At the same time, it is often planted near the house, where under its lush crown you can hide from the bright sun's rays. It has a decorative appearance in single plantings.

One of the ways of reproduction of taxa of the genus *Salix* is seed, but they also have a high ability to root propagation. At the same time, artificial generative propagation of plants of the mentioned genus is used in breeding work [1, 29].

The seed method of propagation of plant organisms of the genus *Salix* is of production value for introduced cultivars. Ornamental plant forms transmit their properties to their descendants only through root propagation. In nurseries, plant organisms of the genus *Salix* are propagated vegetatively. At the same time, due to the large number of root buds, taxa of the genus *Salix* can reproduce by various methods of asexual reproduction - lignified and green cuttings, mere cuttings, stakes, particle formation, etc.

Plants of the mentioned genus, due to their biology, are able to reproduce both by vertical and horizontal cuttings. Vertical cuttings are formed in places of siltation. In the nursery business, the cultivation of seedlings by cuttings is practically not carried out.

Figure 8. Planted cuttings of Salix

The main planting material for representatives of the genus *Salix* is cuttings (Fig.
8), rods, branches, stakes. The simplest, most convenient and economically feasible way of propagating plant organisms of the genus is lignified microshoots [1].

Experimental studies on the influence of microshoot size on their reproductive capacity and further plant growth of the main cultivars of the genus *Salix* were carried out by Ya. D. Fuchylo and M. V. Sbytna [33]. The results of their studies showed that the optimal length of cuttings for some species is 20-30 cm. These scientists also found a correlation between the size of the microshoot, the height of the annual planting material and the number of formed lateral shoots on the stem.

According to N. Yu. Vysotskaya [1], the optimal size of the cutting is 25-30 cm and a diameter of 7 - 10 mm.

Some scientists suggest using microshoots approximately 0.30 m long and 6-13 mm thick for root propagation [33].

At the same time, the vast majority of scientists who have studied the features of root propagation by cuttings of some cultivars of the genus *Salix* do not recommend harvesting cuttings from the upper part of the branch. Experiments on the influence of shoot type on root formation ability were conducted by Ya. D. Fuchylo and M. V. Sbytnaya [33], and for certain taxa of this genus they found that the number of rooted microshoots was higher when taken from the medial and basal parts of the stem. The above-mentioned researchers, in their experimental work, also analyzed the influence of exogenous hormonal compounds on the processes of callus and coregenesis in microshoots, and subsequent plant growth. They found that indolyloleic acid was the best root stimulant for some members of the *Salix* genus, when cuttings were taken from the medial part of the branch. Cuttings from the apical part of the stem have a long growth period and are not able to lignify before the onset of winter cold. In addition, they are significantly thinner than microshoots from the medial and basal parts of the stem and have a lower nutrient content, which negatively affects root formation and further plant growth.

There are two points of view regarding the period of cuttings of representatives of the genus *Salix*. Some researchers believe that to reduce the intensity of work in the spring period, it is advisable to plant microshoots in the first decade of November [28, 31]. At the same time, the vast majority of experimenters unanimously prove that cuttings can be planted both in spring and autumn, but they prefer spring planting dates, since planting material planted in the cold season takes root worse and is affected by low temperatures [33].

Vysotska N. V. [1] in her experimental work proved that the autumn and spring terms of planting cuttings are practically equivalent.

Fuchylo Ya. D. and Sbytna M. V. [33] recorded that the reproductive capacity and growth of planting material are influenced not only by the period of harvesting and planting microshoots, but also by soil fertility indicators. At the same time, on soils that contain a sufficient amount of nutrients and in humid areas, these indicators are better [23].

Regarding the problem of using plant growth regulators, in the experiments of Ya. D. Fuchyla and M. V. Sbytna [13] it was found that treatment of *Salix viminalis* cuttings with indolyloleic acid negatively affects the course of callus and coregenesis processes, as well as their further growth, since rooting in the control variant was significantly higher and the height of the plants was greater than when treated with growth regulators.

Fuchylo Ya. D. and Sbytna M. V. [13] found that *Salix caprea* belongs to easily rooted cultivars. For root-owning propagation of this taxon, it is advisable to prepare cuttings from the basal part of the stem in spring, approximately 15 cm long and 8-20 mm in diameter. It is advisable to root the named species without using hormonal compounds. However, some scientists deny that this method can be used to root individual decorative forms of the named taxon [9]. Considering the above information, in the process of plant propagation by cuttings, it is advisable to take into account not only the botanical characteristics of the taxon, but also the varietal ones. In addition, experimenters do not suggest cutting microshoots from the upper part of the stem during the propagation process. They suggest treating the prepared cuttings with a heteroauxin solution before planting, and before that, soaking them in water for 20 hours. Planting is carried out in a nutrient substrate under conditions of adequate water supply.

In general, exogenous compounds of hormonal nature do not significantly affect the processes of callus and coregenesis, since the difference between rooting in the search variant and the control was up to 1-3%. The minimum rooting value was observed in the following taxa: *S. caprea* and *S. cinerea*. It is likely that the above-mentioned cultivars need to be propagated generatively.

In the conditions of the stationary polygon of the BNAU, the influence of the type of cutting material on the survival of microshoots in different taxa and decorative forms of representatives of the genus *Salix* was analyzed. At the same time, in the process of performing the search work, it was found that the optimal size of the microshoot for most cultivars is 15 cm, but for some representatives (*S. matsudana* Tortuosa*, S. capusii, S. argeraceae, S. elaeagnos, S. viminalis* Ternopilska), the rooting ability of cuttings was more than 85%, with a length of cutting material of approximately 20 cm.

Grafting of planting material in nurseries is carried out only for standard forms and clones of the genus *Salix*. At the same time, Pravdin L. F. [33] carried out grafting of *S. caprea* by the method of copulation onto the rootstock of *S. dasyclados*. Grafting was carried out in the second decade of February, and the plants were stored in the snow until spring planting.

A new and promising method of propagating ornamental plant taxa and their forms is the method of microclonal plant propagation, which makes it possible to obtain a sufficient amount of healthy genetically homogeneous planting material regardless of external factors. In vitro culture of plant organisms of the genus *Salix,* along with cuttings, is attracting interest. The technology of isolated tissues has certain advantages: it is the only way to produce viable planting material of promising varieties and their decorative forms. This method provides a high reproduction rate [33].

Salix has long been attributed magical properties - protection from all kinds of misfortunes and evil spirits; it was used to treat headaches, rheumatism, fever, gastrointestinal diseases, etc. [13]

The meaning of the worship of *Salix* is that the tree should convey strength, health and beauty to the human body or animal. This custom existed among various nationalities. It was carried out in the vast majority in the spring, when the vegetation period begins for trees, they bloom, gain energy themselves and, according to belief, are able to transfer it to others.

The sacred *Salix* is highly revered among the Ukrainian people. "It is a sin to trample on a consecrated *Salix*," and therefore even the small shoots that remained after consecration were burned on fire [9]. Consecrated *Salix* branches were given magical power. In the spring, cattle were beaten with consecrated *Salix* branches - "so that evil spirits would not cling to the animals." In addition, consecrated *Salix* branches were thrown out into the street during hail - "to stop the hail" [18].

Salix has a special significance in medicine. In case of diseases of people or animals, folk healers boiled consecrated *Salix* together with herbs and gave such liquid to drink to the sick animal or person - in the full sense that it would help. The head is washed with the infusion of consecrated *Salix* and this is used to treat headaches. In addition, consecrated *Salix* is used to treat rheumatism and fever, and fever symptoms are reduced.

Crushed *Salix* leaves are sprinkled on wounds, and tinctures from the leaves are used for intestinal diseases. In addition, it is also used in medicine. *Salix* bark in light infusions is used for rheumatic pains of muscles and joints. In this case, it is best to drink its infusion for 15 days. Decoctions of the bark are used for fever and febrile conditions associated with high nervous tension. The bark of white *Salix* is part of some medicines (passiflorin).

S. caprea, a taxon of *Salix*, is used for medicinal purposes.

According to popular belief, *S. caprea* was cursed by God because it was used to make nails for the cross on which Jesus Christ was crucified. In addition, according to legend, an evil spirit resides in the dry wood of *Salix*; hence the saying: "I fell in love with a dry willow like the devil!" *S. caprea* is widely distributed in Ukraine, especially in wooded areas. It is characterized by " catkins ", as well as short and wide leaves.

Figure 9. Salix bark

Bark (Fig. 9) is harvested for extract production at the end of the growing season, and from *Salix triandra* - from the beginning of August, when the bark contains the largest amount of tannin. To obtain bark, 2-4-year-old *Salix* trees and branches are cut and sprinkled with soil mixture. In the spring, they are placed in water, after which the bark is harvested, which is easily separated from the stem. The collected bark is dried in the shade. In this case, the tannin content in the bark should be more than 6%, its optimal humidity is 16%, and it should not contain wood. During the raw material procurement period from October 1 to May 1, bark with a moisture content of up to 21% is allowed to be purchased. It must be free of signs of mold and rot, and must not have wormholes. The outer side of the bark should be longitudinally grooved, rough or smooth, gray, brown or grayish-green in color, and the inner side should be smooth, clean, without wood impurities, bright pink, bright straw, bright brown in color. Raw materials are accounted for in tons, and the calculation is made for a bark moisture con-tent of 16%.

For medical purposes, *Salix* bark is harvested in early spring before the phase of swelling and budding, when it easily lags behind the wood. On last year's branches, bark incisions are made every 30 cm, and the bark is easily removed. After removal, the raw material is immediately dried on a cloth, spreading it in a thin layer. The bark is dried under a canopy. The dried medicinal raw material does not bend, it breaks with a crack. At the same time, impurities are excluded from the material.

Figure 10. Furniture

For the production of furniture (Fig. 10) *Salix* rods are used, which are peeled from the bark, with a thickness of the lower cut up to 11 mm, as well as peeled sticks with a thickness of 1.2 to 4.5 cm.

Figure 11. Use of Salix vines

In the manufacture of wickerwork (household items (Fig. 11), baskets, women's handbags) peeled *Salix* rods with a thickness at the base up to 20 mm are taken. The vine is harvested in the autumn-winter period. At the same time, for production purposes, one-year growth is taken, which should be even, flexible, without damage and knots. To remove the bark, the vine (one-year growth) is tied into bundles and placed in a reservoir to provoke sap flow, while the bark is easily separated. In specialized workshops, before removing the bark, the one-year-old growth is treated with hot steam or boiled in cauldrons. The prepared rod eventually acquires a brownish-pinkish color from the coloring and tanning compounds contained in the bark. The vine is bleached with chlorine or sulfuric acid. *Salix* moisture content of raw materials for wickerwork should be 14-16%, and *Salix* moisture content in finished furniture should not exceed 17%.

Conditions and methods of conducting research. Research on the cultivation of *S. matsudana* planting material for landscaping was carried out in the conditions of the cultivation facility and open ground of the Edelweiss garden center in 2025.

The material for growing plants with an uninjured root system was stem microshoots (Fig. 12). Cuttings were harvested from trees approximately 15 years old.

Figure 12. Planting material

Planting material was harvested from the medial part of a one-year-old branch before the bud swelling phase. The size of the cutting was 13-15 cm. In addition, they were placed in water for 3 hours. Rooting of the planting material was carried out in a greenhouse, where 1.0 l containers were placed. The pots were filled with a substrate that included peat and river sand. 100 pcs. cuttings were planted for each option.

The experimental design included options where the factors were the thickness of the planting material and the degree of light supply. The planting depth of the planting material was 10-11 cm.

The studies were conducted according to the following scheme:

Factor A – natural light conditions: 1) control (5 mm); 2) 7 mm; 3) 10 mm; 4) 13 mm. Factor B – shading conditions: 1) control (5 mm); 2). 7 mm; 3) 10 mm; 4) 13 mm.

At the end of May, pots with cuttings were moved to open ground, where they remained until the end of the growing season.

In the second decade of September, measurements of morphometric indicators of grown plants were carried out: the size of the aboveground part, the mass of the root and aboveground system.

The research was carried out according to the methodology for plant propagation [3, 27].

Research results. The root-owning method of propagation for many plants is the only means of preserving valuable properties and characteristics, and also intensifies the process of growing high-quality planting material.

There are artificial reproduction, which occurs under the influence of human activity, and natural, which is carried out without the human factor. During vegetative reproduction, all biological and economically valuable features and characteristics are transmitted to the generation, which provides the opportunity to reproduce plants and their decorative forms. The process of root system formation is considered as a complex of various histological, physiological and biochemical processes [32]. At the same time, roots in microshoots are formed in different tissues. In lignified microshoots, roots appear in the cambium zone.

The main importance for coregenesis in stem microshoots and their further growth is played by climatic factors (lighting, temperature, humidity of air and substrate) and edaphic factors, and therefore it is necessary to create favorable conditions for the growth and development of cuttings.

According to the results of the search work, a corresponding dependence was found, that with an increase in the thickness of microshoots, the height of the planting material improves (Table 1 and Fig. 13).

When using cuttings with a diameter of 5 mm, the height of the plants was within 42.0-58.0 cm, while in the experimental variant (13 mm) - 84-177 cm, which is 2-3.1 times less. At the same time, a significant difference was recorded between the experimental variants and the control. Considering the above, according to the results of the information obtained, it was found that planting material with a thickness of 10-13 is optimal.

Table 1. The influence of some factors on biometric indicators of plants

Option	Lighting Level	Indicators				
		Plant height, cm	Weight, g			
			roots	% to control	above-ground part	% to control
Control (5)	Shading	42,0	5,4	-	6,3	-
	Natural Lighting	58,0	8,09	+ 149,8	21,76	+ 345,4
7	Shading	68,0	9,7	-	13,4	-
	Natural Lighting	72,0	12,44	+ 128,2	32,95	+ 245,9
10	Shading	79,0	12,7	-	21,6	-
	Natural Lighting	104,0	18,25	+ 143,7	48,49	+ 224,5
13	Shading	84,0	16,9	-	29,1	-
	Natural Lighting	177,0	29,13	+ 172,4	66,25	+ 227,7

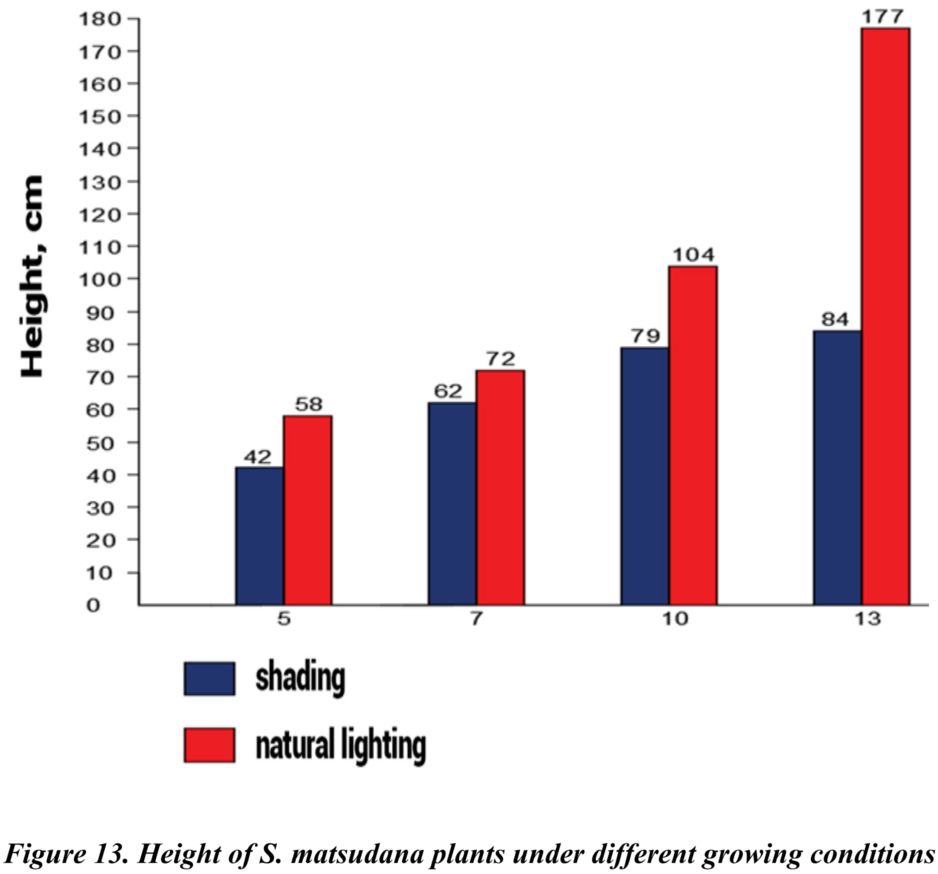


Figure 13. Height of S. matsudana plants under different growing conditions

In addition, it is advisable to pay attention to the fact that the intensity of lighting of planting material affects the size of plants.

Thus, it can be said that the degree of illumination and the thickness of the cuttings play a significant role in improving the quality of planting material.

In addition, the study examined the relationship between the thickness of the planting material and the mass of the root system (Fig. 14). When harvesting cuttings with a thickness of 13 mm, the weight of the root system was 16.9-29.13 g, which was 21.04 and 11.5 g higher than the control variants, where microshoots with a thickness of 5 mm were used. At the same time, the reproductive ability of the variants was reliable.

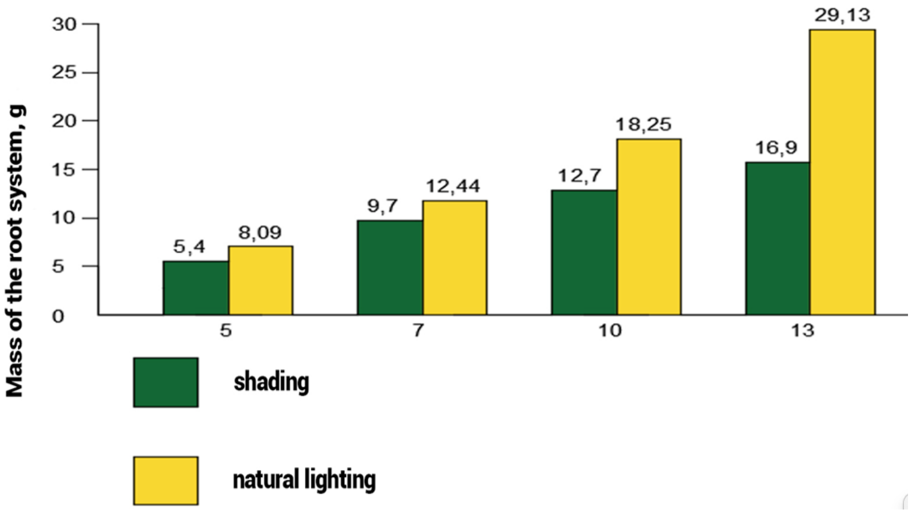


Figure 14. Weight of the root system of S. matsudana plants

According to the table, it can be stated that the weight of the root system of planting material is affected by the degree of light availability and the thickness of the planting material. Thus, microshoots with a thickness of 13 mm form a branched root system compared to the variant where cuttings with a thickness of 5 mm were planted, which accordingly affects the growth processes of *S. matsudana* plants and the absorption of nutrients.

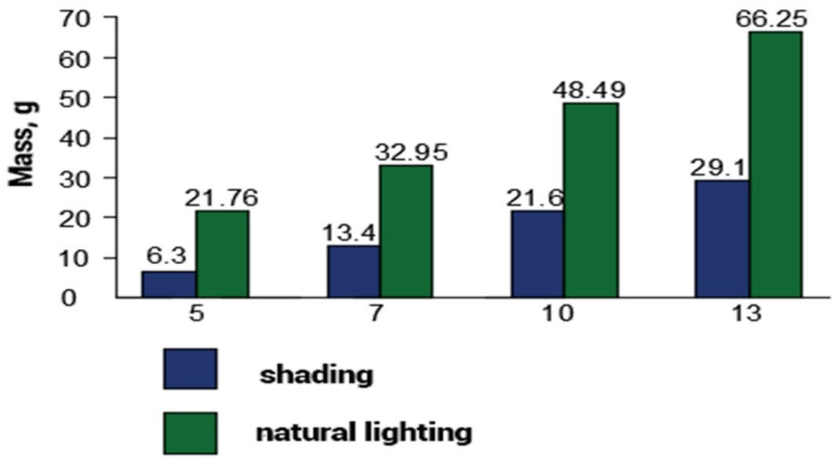


Figure 15. Mass of the above-ground part of the planting material

In the process of analyzing the influence of cutting thickness and degree of light supply on the mass of the aboveground part of *S. matsudana* self-rooted seedlings (Fig. 15), a significant difference between the variants was recorded. The weight of the aboveground part of the plants ranged from 6.3 to 66.25 g. The mentioned indicator in the search variants was 22.8-44.49 g higher compared to the control.

It was found that the plants of the control variant had a worse named indicator than the experimental ones. In the process of research work it was found that under optimal lighting conditions and an increase in the thickness of the cutting material, an improvement in the weight of the above-ground part occurred, which had a corresponding role in biochemical processes, such as the exchange of organic compounds and photosynthetic activity, and also provided favorable conditions for the further development of the plant organism.

Thus, it can be said that the thickness of the planting material and growing conditions have a significant impact not only on the height of *S. matsudana* plants, but also on their weight. It was found that the maximum plant sizes were found in the search variant, where the thickness of the planting material was 13 mm.

From the above, it is reasonable to conclude that under the conditions of own-root cultivation of planting material with an uninjured root system, it is necessary to plant microshoots 13 mm thick.

The genus *Salix* is numerous and complex in its taxonomy. Its taxa readily cross-pollinate with each other, forming hybrid forms that are difficult to identify. In addition, approximately 350 representatives of the genus are known, several of which are widely used in landscaping [9, 14-15, 17, 19].

Salix is an unpretentious tree or shrub used in ornamental gardening for landscaping parks and squares.

Long before the advent of the Christian religion, people revered *Salix.* Its shoots were used as a remedy against evil spirits, and a broom made of branches served as a talisman in the house. Special importance was attached to this breed, since it was believed that it has great vital energy, blooms earlier than other trees, and also receives spring energy from the sun.

Figure 16. Salix in design

Especially good conditions are for *Salix*, where there is moisture, near large or small reservoirs (Fig. 16). It is valued for its fairly intensive growth and original crown shape, which allows it to be used in creating appropriate garden and park compositions [22].

Figure 17. Single plantings of S. matsudana

S. matsudana has a spreading crown and drooping shoots. It looks great both in single plantings (Fig. 17) and in compositions (Fig. 18). This plant will decorate the site in the English style, which involves asymmetry, maximum approximation to the natural environment, as well as free planning.

Figure 18. Group plantings of Salix

Before planting *Salix*, it is necessary to choose a place in the garden plot. Decorative taxa require sheltered from the wind, slightly shaded or sunny places.

With a lack of light, *Salix* grows satisfactorily, in decorative-deciduous forms the color of the leaves loses its saturated color. It feels good on nutritious, aerated and moist soils with close groundwater levels.

The retail network mainly sells planting material with an undamaged root system, which is planted during the growing season - from the third decade of March to the first decade of November. At the same time, the earthen lump should not be dry, as this affects the survival of the seedlings. Planting material with an open root system requires planting before the buds swell and bloom or in the second decade of October. Highly decorative forms with relatively poor winter hardiness are recommended to be planted in the spring season so that they can grow stronger during the summer. The root system of the planting material should be freely placed in the planting pit. To improve soil fertility, humus is added to the pit. After planting, the soil is compacted and watered abundantly.

The soil around the seedlings is mulched with humus with a layer of about 10 cm. Mulch creates optimal conditions for growth and also prevents intensive evaporation of moisture.

During periods of drought and heat, *Salix* requires intensive watering, it is advisable to spray the crown of weeping forms, *Hakuro Nishiki* especially likes a “shower”.

After planting, the planting material is sensitive to moisture deficiency, and therefore in the first year requires constant irrigation. Drying of the soil is not allowed.

The vast majority of *Salix* cultivars and ornamental forms are quite winter-hardy, but in conditions of low winter temperatures, the shoots of young plants may freeze. To avoid the aforementioned problem, it is advisable to insulate young plants for the first 3 years.

Ornamental *Salix* look attractive if fertilized every year. The amount of nutrients depends on the size of the tree, its growth rate and soil fertility.

The first feeding with complex fertilizer is carried out at the end of March after pruning, and the next time - in the first decade of July. Humus or long-lasting fertilizers are applied once during the growing season – the third decade of March, since use at a later date worsens the winter and frost resistance of trees. An important element of *Salix* care is pruning, which strengthens the tree, improves its condition and creates the opportunity to form a crown. Without the above-mentioned technological operation, the plant forms an unattractive crown that loses its decorativeness.

Crown formation begins in the first growing season after planting the planting material. *Salix* tolerates pruning well, which stimulates the growth of new lateral branches and limits excessive growth. The technological operation is carried out at any time of the year, but it is best to carry out a strong shortening of the shoots in spring before the leaves appear.

After planting the seedlings, the branches are cut, leaving about 0.20 m in length or a few buds at the base. The cut is made slightly above the growth point, about 4 mm.

In subsequent seasons, all shoots of bush *Salix* are pruned to the point where they started their growth last season. The plant will respond to annual pruning with abundant flowering and intensive growth.

Vertical shoots of trees are removed in spring, leaving a central conductor. During the growing season, after pruning, the tree gives a powerful growth of new shoots, forming a dense, highly decorative crown. Cuts of large branches are covered with garden pitch or oil paint with the addition of topsin.

Standard *Salix* are pruned several times during the warm season, but the last cut is made at the end of the third decade of July.

Technological measure ensures crown compaction, stimulates the growth of new shoots. In weeping forms, branches are shortened to length depending on the needs of the owner.

To maintain the phytosanitary condition of *Salix*, sanitary pruning is also carried out. The thickened crown is thinned out so that the tree receives enough light, and diseased, weak and damaged branches are removed. After pruning, it is advisable to water and fertilize the tree abundantly.

Systematical removing of the root growth that grows from the root system of trees grafted onto the stock is recommended.

Conclusions and Suggestions

1. The climatic and soil conditions of the Sumy region are favorable for the production of *S. matsudana* planting material.

2. *S. matsudana* should be propagated by lignified microshoots, which are harvested from the middle part of the branch before the bud swelling phase. The optimal length of planting material is 13-15 cm.

3. It has been proven through research that the quality indicators of the planting material of the experimental species are influenced by the thickness of the cutting and growing conditions.

4. Under conditions of insufficient lighting, the height of the plants was within 42.0-84.0 cm, which is 17.0-93.0 cm less than in the search options.

5. When harvesting cuttings with a thickness of 13 mm, the mass of the above-ground part was 29.1-66.25 g, which is 3.05 and 4.62 times more than planting material with a thickness of 5 mm.

6. *S. matsudana* is a fast-growing tree species, which is used to form recreational areas as single and group plantings.

For growing *S. matsudana* planting material, we suggest preparing cuttings 10-13 mm thick. Given the botanical and ecological characteristics of this taxon, it is necessary to use it when creating recreational facilities.

REFERENCES

1. Vysotska N. Yu. (2014) Technologies and agricultural techniques for creating bioenergy plantations of poplars and willows in Ukraine. *Bulletin of the KhNTUSG*, Issue 155, P. 122-126.
2. Golyaka D. M., Bilous A. M., Golyaka M. A., (2018) Phytomas of shrubby willows in natural phytocenoses of Chernihiv Polissya: monograph. Kyiv: NUBiP of Ukraine, 227 p.
3. Gordienko M. I., Maurer V. M., Kovalevsky S. B., (2000) Methodological guidelines for the study and research of forest crops. Kyiv, 101 p.
4. Gordienko M. I., Fuchylo Ya. D., Boychuk A. F., (2002) Shrub willows of the plain part of Ukraine. Kyiv: Publishing house of the Institute of Agrarian Economics, 174 p.
5. Gromova O. P., Gorelov O. M., (2014) Decorative willows of the collection of the National Botanical Garden named after M. M. Hryshko of the NAS of Ukraine, their pests and protective measures. *Introduction to plants,* No. 3, P. 80-84.
6. Znoyko O. P., (1989) Myths of the Kyiv land and ancient events. Kyiv, 304 p.
7. Zayachuk V. Ya.. (2019) Dendrology: a textbook. Kyiv: Higher School, 675 p.
8. Ishchuk L. I., (2013) History of the study of species of the genus Salix L. in Ukraine and prospects for their further research. *Autochthonous and introduced plants of Ukraine: collection of scientific works*, Issue 9, P. 18-22.
9. Ishchuk L. P., (2013) Peculiarities of creating mixed groups using representatives of the genus Salix L. *Urban planning and territorial planning: scientific and technical collection*. Kyiv: KNUBA, Issue 48, P. 196-200.
10. Ishchuk L. P., (2014) Assortment, cultural features and prospects for the use of arctic-montane species of the genus Salix L. *Scientific Bulletin of the National Forestry University of Ukraine: collection of scientific and technical works*. Lviv: NLTUU. Issue 24.4, P. 28-35.
11. Ishchuk L. P., (2013) Features of the use of representatives of the family Salicaceae Mirbel. in the design of landscape compositions. *Scientific Bulletin of the National Forestry University of Ukraine: Collection of Scientific and Technical Works*. Lviv: NLTUU. Issue 23.9. P. 197-202.
12. Ishchuk L. P., (2015) Prospects for expanding the range of species of the genus Salix L. for green construction in Ukraine. *Protection of biodiversity and historical and cultural heritage in botanical gardens and arboretums: Materials of the international scientific conference*. Uman: Publisher "Sochinsky", P. 59-62.
13. Ishchuk L. P., (2015) Pharmaceutical properties of autochthonous species of the genus Salix L. *Agrobiodiversity for improving nutrition, health and life quality: Scientific proceedings of the international network AgroBioet of the institution and researcher of international research, education and development programme "Agrobiodiversity for improving nutrition, health and life quality*" (20-22 august). Nitra, Parn I, P. 280-283.
14. Ishchuk L. P., (2016) Use of willows (*Salix* L.) in phytodesign. *Modern trends in the preservation, restoration and enrichment of phytodiversity of botanical gardens and arboretums, dedicated to the 70th anniversary of the dendrological park "Olexandria" as a scientific institution of the NAS of Ukraine* (23-25 May 2016). Bila Tserkva, P. 170-173.

15. Ishchuk L. P., (2017) The use of willow (Salix L.) and poplar (*Populus* L.) in flower arrangements. *Autochthonous and introduced plants*, Issue 13. P. 23-30.
16. Ishchuk L. P., Ishchuk G. P., (2017) Features of forming topiary from spherical weeping and stunted species and cultivars of the genus Salix L. *Current problems of landscaping settlements: education, science, production, art of landscape formation: materials of the III International Scientific and Practical Conference* (May 25-26, 2017, Bila Tserkva). Bila Tserkva, P. 64-66.
17. Ishchuk L. P., (2018) The role of species of the genus Salix L. in the formation of riverside landscapes of lowland rivers. *Collection of Sciences. Proceedings of the All-Ukrainian Scientific and Practical Conference with International Participation on the 5th Anniversary of the National Nature Park "Male Polissya"* (Slavuta, May 23-25, 2018). Slavuta, P. 198-202.
18. Ischuk L. P., Ischuk G. P., (2018) Willow in the ethnocultural traditions and customs of Ukrainians. *Ethnobotanical traditions in agronomy, pharmacy and garden design: materials of the International Scientific Conference dedicated to the Year of Cultural Heritage in Europe* (July 4-7, 2018). Uman: Publisher "Sochinsky M. M.", P. 100-108.
19. Ischuk L. P., Ischuk G. P., (2018) Plants of the *Salicaceae* family Mirbel. in phytodesign. *Problems of preservation and enrichment of plant diversity in botanical gardens and arboretums: materials of the All-Ukrainian scientific conference*. Uman: Publisher "Sochinsky M. M.", P. 194-198.
20. Kokhno M. A., (2002) Dendroflora of Ukraine. Wild and cultivated trees and shrubs. Angiosperms. Kyiv: Publishing house "Phytosociotsentr", 448 p.
21. Kruglyak Yu. M., (2010) Water regime and drought resistance of leaves of species, forms and hybrids of the genus *Salix* L. *Introduction to plants*, No. 1, P. 85-89.
22. Kruglyak Yu. M., (2011) Bioecological features of species, forms and hybrids of bush willows (*Salix* L.) in the conditions of the Right-Bank Forest-Steppe of Ukraine: author's abstract. dissertation for the degree of science. degree of candidate of biological sciences, speciality: 03.00.05 botany. Kyiv, 19 p.
23. Kuntsyo I. O., Gumentyk Ya. M., (2013) Growing energy willow as a raw material for the production of solid biofuels in the conditions of the Forest-Steppe of Ukraine. *Scientific works of the Institute of Bioenergy Crops and Sugar Beet*, Issue 19, P. 59-62.
24. Kuznetsov S. I., Levon F. M., Klymenko Yu. A., (2000) Current state and ways to optimize green spaces in Kyiv. *Introduction and green construction*. Bila Tserkva, P. 90-104.
25. Lukashchuk G. B., (2020) Dendrology. Lviv: Lviv Polytechnic, 348 p.
26. Mazurenko N. A., Maurer V. M., (2013) Distribution of representatives of the genus Salix L. in Ukraine and prospects for their use in landscaping. *Scientific Bulletin of the National University of Life Sciences of Ukraine. Series. Forestry and ornamental gardening*. Issue 187, Part 1, P. 93-99.
27. Maurer V. M., Kushnir A. I., (2008) Methodological recommendations for the propagation of woody ornamental plants of the Botanical Garden of the National University of Life Sciences of Ukraine. Kyiv: NULiP, 55 p.
28. Maurer V. M., Pinchuk A. P., (2013) State and quality of forest restoration work in Ukraine and ways to improve them. *Scientific Bulletin of the National University of Life Sciences of Ukraine. Series "Forestry and ornamental gardening"*, Issue 187 (11), P. 328-334.
29. Rogovsky S. V., Masalsky V. P., Lavrov V. V., (2018) Modern technologies in nurseries, a teaching and methodological manual for studying the discipline for students of the Faculty of Agrobiotechnology. Bila Tserkva, 192 p.
30. Sudarikova Yulia, (2019) Exotic trees, bushes and vines in the landscapes of Ukraine. Kyiv, 336 p.
31. Fuchylo Ya. D., Sbytna M. V., (2009) Willows of Ukraine (biology, ecology, use): monograph. Kyiv: Publishing house "Logos", 200 p.
32. Maurer V. M., Pinchuk A. P., Boboshko-Bardyn I. M., Kosenko Yu. (2019) AND. Decorative nursery: a textbook. Kyiv: Profknyga, 296 p.
33. Fuchilo Ya. D., Sbytna M. IN., (2019) Willows of Ukraine (biology, ecology, use): monograph. Kyiv: Logos, 200 p.

PROSPECTS FOR THE USE OF *HEMEROCALLIS* X *HYBRIDA* IN PHYTODESIGN AND LANDSCAPE ARCHITECTURE TECHNOLOGICAL ASPECTS OF CULTIVATION

Osmachko Olena
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0003-0591-2650

Bakumenko Olha
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0003-1625-7401

Kriuchko Liudmyla
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0003- 0528-210X

Introduction. Under the modern conditions of globalization and intensive urbanization, the role of urban green infrastructure is transforming from purely aesthetic to functional and ecological. Modern landscape architecture requires plants that are capable not only of creating a visual effect but also of withstanding significant anthropogenic pressures: temperature inversions, moisture deficiency, soil salinity, and high concentrations of heavy metals in the air [1, 2].

Today, the hybrid daylily (*Hemerocallis* × *hybrida*) is one of the most versatile and promising crops. The history of daylily breeding has progressed from species forms to complex tetraploid hybrids, with over 80,000 registered cultivars. This creates an unprecedented resource for phytodesign: ranging from miniature forms (up to 20 cm) for rock gardens to giant spiders (exceeding 120 cm) [3-7].

An analysis of global experience reveals a transition from traditional flower beds to complex sustainable phytocenoses. The daylily fits perfectly into the concept of low-maintenance landscapes. Due to their robust root system, they serve as excellent groundcover plants that prevent erosion, while their dense leaf rosettes suppress weed growth [4, 8, 9].

Advanced techniques, particularly *in vitro* micropropagation, facilitate the swift introduction of emerging cultivars into the commercial market. The implementation of drip irrigation systems and precision fertilization transforms daylily cultivation into a high-tech sector of the nursery industry [10-15].

Integrating daylily displays into urban parks enhances the recreational appeal of these spaces and supports the psychological well-being of residents. Economically, this serves as a sustainable long-term investment, given that daylilies maintain their aesthetic quality for 10 to 15 years without requiring relocation [16-21].

Problem statement. Although the genus *Hemerocallis* has been extensively researched, a significant gap remains between its theoretical potential and its practical application in landscape design. There is a marked disconnect between the vast diversity of global cultivars and the limited selection found in local nurseries. Consequently, most landscaping projects rely on a narrow range of varieties, hindering the implementation of contemporary phytodesign strategies – such as monochrome gardens or landscapes designed for prolonged flowering cycles [22-25].

A pressing issue is the adaptation of modern tetraploid hybrids of foreign breeding to the specific climatic conditions of Ukraine, particularly to sharp temperature fluctuations during the winter and extreme summer droughts.

The lack of site-specific cultivation protocols results in significant mortality rates during the initial years of plant establishment [26-30]. Within the realms of interior phytodesign and container gardening, there is a notable absence of scientifically substantiated guidelines for utilizing daylilies as containerized crops. Questions concerning substrates, lighting regimes, and growth regulation within limited soil volumes remain open [31-34].

Consequently, there is a pressing need for a comprehensive study that integrates an assessment of the ornamental traits of the latest *Hemerocallis* × *hybrida* cultivars with the establishment of optimized cultivation techniques tailored for modern urban environments.

The aim of this study is to conduct a comparative analysis of modern *Hemerocallis × hybrida* cultivars within landscape architecture and phytodesign systems based on key morphological indicators. Furthermore, it seeks to perform a comprehensive assessment of their decorative qualities using container cultivation technology at the TOV SP «Demetra» nursery to optimize the assortment available for phytodesign and landscape architecture.

The nursery operates as an independent enterprise, specializing in container-grown planting material. The production cycle integrates mechanized technological processes with advanced fertilization and plant protection protocols.

The nursery is structured into two primary zones: the production area and the auxiliary area. The production sector is dedicated to the cultivation of ornamental, fruit, and berry nursery stock. Complementing this, the auxiliary section provides essential support, encompassing organizational, administrative, and protective functions

Research Methods. To obtain scientific data regarding the introduction and aesthetic evaluation of *Hemerocallis* cultivars, diverse methods for the collection and analysis of morphological and ornamental traits are utilized. Field observations are systematically conducted within experimental plots to monitor these characteristics. These plots were selected to reflect the typical conditions of the forest-steppe zone, facilitating an accurate assessment of plant adaptation to the regional climate and soil.

The primary methodology for assessing ornamental traits involves a comparative analysis of specific plant components, including scape height, flower diameter and morphology, foliage dimensions, and clump density. This approach facilitates the creation of a technical profile for each cultivar, providing an exhaustive description of individual characteristics. Moreover, it identifies the specific cultivation technologies that most effectively enhance the plants' aesthetic qualities [35, 36, 37].

The research methodology focuses on evaluating the ornamental traits of specific daylily cultivars grown using container cultivation technology. The assessment is based on several key indicators: flower color and morphology, the duration and intensity of the blooming period, flower and leaf dimensions, plant and scape height, and clump density [38, 39]. The resulting data are subsequently processed using statistical analysis [40].

In addition to morphological analysis, the plants' adaptive traits to local growing conditions are thoroughly evaluated. These parameters encompass heat and drought tolerance, natural propagation capacity, and resistance to pests and diseases. Based on the study's findings, cultivars that exhibit superior ornamental qualities under container cultivation and demonstrate suitability for the regional climate are selected [41]

Consequently, a holistic methodology – integrating comprehensive data collection, morphological assessment, and systematic observation – юensures objective and scientifically substantiated findings. These results provide a robust basis for determining the suitability of *Hemerocallis* cultivars for landscaping both urban environments and private estates within the specific conditions of Ukraine's Forest-Steppe zone.

The research material consisted of *Hemerocallis × hybrida* cultivars grown on the premises of the Demetra ornamental nursery.

Specifics of daylily cultivation technologies. To date, five main methods of daylily cultivation are recognized. The first approach is traditional open-field cultivation, which remains the most prevalent method for growing daylilies. Its primary advantages include providing natural conditions for root system development, lower capital expenditures for equipment, and the scalability to manage large plant populations. Conversely, the method entails several drawbacks, such as vulnerability to weather fluctuations, an increased risk of pest and disease pressure, seasonal flowering constraints, and the difficulty of maintaining precise control over soil moisture and nutrient levels across expansive areas.

Daylilies cultivated in open fields develop extensive root systems and demonstrate superior frost resistance relative to other production methods. Ideal cultivation sites are open, sunny locations with adequate air circulation. Systematic irrigation is critical, especially during stages of vigorous growth; such applications must be substantial enough to ensure soil moisture penetrates to a depth of 50 cm [42].

The second method involves container cultivation using individual pots of varying capacities. Key advantages include plant mobility – allowing for seasonal relocation – and precise control over substrate quality, irrigation, and fertilization. This method is particularly suitable for confined spaces and reduces the prevalence of soil-borne pathogens. However, drawbacks include the need for intensive maintenance, the risk of root zone hyperthermia in dark containers, and higher operational costs. Recommended container volumes range from 5 to 15 liters, contingent on cultivar height, and must feature drainage holes to prevent waterlogging. Ideal materials include ceramics, plastic, or geotextile bags. The substrate should be a lightweight, aerated blend of soil, humus, peat, and sand (2:1:1:1 ratio), potentially augmented with vermiculite or perlite. Because moisture evaporates and nutrients leach more rapidly in containers, more frequent irrigation and fertilization are required compared to in-ground cultivation [43, 44].

The third method employs protected-ground cultivation within greenhouses and hotbeds under controlled environmental conditions. This approach offers the advantage of regulating temperature, humidity, and lighting, which allows for manipulated flowering schedules and protection from adverse weather, pests, and pathogens. Integrating modern technologies like drip irrigation and automated climate control enhances efficiency and reduces labor. However, these benefits are offset by high capital expenditures for infrastructure, significant energy requirements for microclimate maintenance, and the need for manual pollination in seed production. Optimal growth occurs between 18°C and 25°C; sharp temperature fluctuations must be avoided to prevent stunted development or diminished ornamental value. As light-demanding crops, daylilies require supplemental lighting (grow lights) during winter. Furthermore, maintaining relative humidity between 60% and 70% is essential for physiological health and the mitigation of fungal diseases [45].

The substrate must be nutrient-dense while maintaining high air and water permeability. An optimal composition consists of a 2:1:1:1 ratio of soil, humus, peat, and sand, which provides the necessary moisture retention and aeration levels for robust root system development [46].

The fourth method is hydroponic cultivation, which involves growing plants in a soil-less medium where nutrients are delivered directly to the roots via an aqueous solution. Common configurations include drip irrigation, Nutrient Film Technique (NFT), and Deep Water Culture (DWC). This approach offers several advantages: precise nutritional management, efficient water and fertilizer conservation, accelerated growth rates, and a diminished risk of soil-borne pathogens. Conversely, its drawbacks include significant capital investment for equipment, the need for specialized technical expertise, and a total reliance on electricity for system operations. Consequently, hydroponics is not standard for commercial daylily production; it is primarily utilized in scientific research or for the cultivation of high-value cultivars [47].

The fifth method is *in vitro* cultivation, or micropropagation – a laboratory-based technique for regenerating plants from small cell or tissue samples within sterile nutrient media. This approach facilitates the rapid production of vast quantities of genetically identical clones [11]. A primary benefit is the elimination of viral pathogens, as plants are sanitized during the process. Additionally, this method is entirely independent of seasonal or climatic fluctuations. However, it requires stringent sterility protocols, highly qualified personnel, and substantial capital investment in laboratory infrastructure. Furthermore, microclones require a critical acclimatization phase before they can transition to open-field conditions. It is most commonly employed for the commercial propagation of rare and high-value cultivars [38].

Research Results. The Impact of Containerized Growth Systems on the Phenological Phases of Hemerocallis. Our research was conducted at the facilities of TOV SP «Demetra», situated within the Forest-Steppe zone of Ukraine. This enterprise specializes in the containerized production of daylilies. For this study, plants were initially grown in 10-liter black containers and subsequently transplanted into 15-liter vessels as they matured.

To prevent waterlogging and subsequent root rot, all containers are equipped with basal drainage holes. While daylilies are adaptable to various soil types, they perform optimally in well-drained, fertile substrates with a neutral to slightly acidic pH (approximately 6,0-7,0). The potting medium utilized for this study consisted of 50% high-quality garden soil for structural integrity and mineral content, 30% humus to provide organic matter and slow-release nutrients, and 20% aerating components. This latter portion included 5% perlite, 5% vermiculite, and 10% coarse sand to enhance drainage and oxygenation. Notably, the inclusion of coarse sand increased container ballast, providing necessary stability for larger specimens.

To facilitate drainage, a 2-3 cm layer of expanded clay was placed at the base of each container. The experimental cultivars were planted in early September 2023; the residual summer warmth in the soil stimulated root development, allowing the plants to become well-established before the first frosts and ensuring successful overwintering. In late October 2023, the daylilies were transferred to a cool, frost-free environment maintained at 5-10°C. A subsequent temperature increase to 10-15°C in early March 2024 triggered the onset of the growing season by late March, evidenced by the emergence of basal shoots, bud enlargement, and the unfurling of young foliage.

Table 1 details the results of our phenological observations regarding daylily growth and development. For the eight studied cultivars, the initial vegetative phase spanned from mid-March to early April. The Stella de Oro variety, classified within the early maturity group, served as the experimental control. Prairie Blue Eyes was the first to initiate vegetation on March 17, while Purple de Oro followed on April 5. This stage was characterized by the activation of dormant rhizome buds, the emergence of narrow young foliage, and the onset of root system development. Additionally, the resumption of photosynthesis facilitated the accumulation of vegetative biomass necessary for subsequent flowering.

The active vegetative growth phase commenced in late April (specifically on April 27, 2024, for the Prairie Blue Eyes cultivar), spanning from the emergence of initial foliage to the onset of scape initiation. This period was characterized by rapid leaf proliferation and the development of a dense basal rosette alongside further root expansion. During this stage, the plants accumulated the essential nutrients required for flower spike formation and prolific blooming. By late May and early summer, the daylilies transitioned into the scape development phase. The first signs of flower stalks emerging from the center of the leaf rosette became apparent, followed by intensive vertical growth and the formation of buds at the apices and in the leaf axils.

The flowering phase commences in late June and early July with the opening of the initial buds, continuing until the final blooms on the clump have expired. Prairie Blue Eyes was the first to initiate flowering, maintaining a duration of 56 days. It was followed by Happy Returns, which began blooming on June 10, 2024, and lasted for 51 days. The varieties Stella de Oro and Chicago Apache tied for third place, each exhibiting a 50-day flowering span. Fourth place was shared by Anna Warner and Apricot Beauty, both with a duration of 45 days. Purple de Oro followed on June 25 with a 36-day blooming period, while Catherine Woodbury was the final cultivar to bloom, starting on July 15, 2024, for 35 days. Our findings suggest a correlation between later blooming onset dates and a reduction in the total flowering duration.

During the anthesis phase, blossoms open sequentially along each scape, with individual flowers typically remaining open for only a single day. The total duration of flowering is contingent upon the cultivar, plant maturity, and prevailing environmental conditions. This stage encompasses pollination and subsequent seed set. Fruit development initiates almost immediately following floral senescence, progressing rapidly within several days.

Table 1. Results of phenological observations on the development of *Hemerocallis* × *hybrida* varieties under the conditions of TOV SP «Demetra», 2024.

Variety	Onset of vegetation	Active vegetative growth phase	Flower stalk formation and growth phase	Blooming phase			Beginning of seed maturation phase	Preparation for dormancy phase	Dormancy phase
				Onset	Termination	Flowering duration			
H. x h. 'Prairie Blue Eyes'	17.03.2024	27.04.2024	24.05.2024	05.06.2024	31.07.2024	56	31.07.2024	01.10.2024	10.11.2024
H. x h. 'Stella De Oro	25.03.2024	05.05.2025	1.06.2024	15.06.2024	05.08.2024	50	05.08.2024	05.10.2024	15.11.2024
H. x h. 'Happy Returns'	20.03.2024	30.04.2024	27.05.2024	10.06.2024	31.07.2024	51	31.07.2024	01.10.2024	10.11.2024
H. x h. 'Chicago Apache'	25.03.2024	05.05.2025	1.06.2024	15.06.2024	05.08.2024	50	05.08.2024	05.10.2024	15.11.2024
H. x h. 'Purple de Oro	05.04.2024	15.05.2024	10.06.2024	25.06.2024	31.07.2024	36	31.07.2024	01.10.2024	10.11.2024
H. x h. 'Catherine Woodbury'	25.03.2024	05.05.2025	1.06.2024	15.07.2024	20.08.2024	35	20.08.2024	20.10.2024	20.11.2024
H. x h. 'Anna Warner'	30.03.2024	10.05.2025	5.06.2024	20.06.2024	05.08.2024	45	05.08.2024	05.10.2024	15.11.2024
H. x h. 'Apricot Beauty'	30.03.2024	10.05.2025	5.06.2024	20.06.2024	05.08.2024	45	05.08.2024	05.10.2024	15.11.2024

Seed maturation occurs over an eight-week period, with ripening dates ranging from July 31, 2024, for Prairie Blue Eyes to August 20, 2024, for Catherine Woodbury. This timeline reinforces a consistent trend in maturation phenology. This phase facilitates sexual reproduction and the accumulation of storage reserves within the rhizome for winter dormancy, which is triggered by declining mean temperatures and photoperiod.

As the senescence phase begins, the foliage loses its chlorophyll, turns yellow, and gradually withers. While above-ground vegetative growth decelerates, the plants actively sequester reserve nutrients within the rhizome in preparation for winter dormancy. This dormancy period commences with the onset of consistent low temperatures and persists until the spring thaw. During this stage, the aerial components – leaves and scapes – die back, and the plants enter a state of physiological dormancy characterized by a significant reduction in metabolic rates. Biological activity is primarily restricted to the rhizome and dormant buds, where essential resources are stored to sustain future development and flowering. In 2024, the transition into dormancy for the various daylily cultivars was recorded between November 10 and November 20.

To derive scientific insights into the introduction and aesthetic evaluation of *Hemerocallis* cultivars, diverse methodologies for the collection and analysis of morphological and ornamental traits are utilized. Systematic field observations are carried out within experimental plots to monitor phenotypic characteristics and decorative performance. These sites are selected to represent the typical environmental conditions of the forest-steppe zone, facilitating a comprehensive assessment of the plants' adaptation to local pedoclimatic factors.

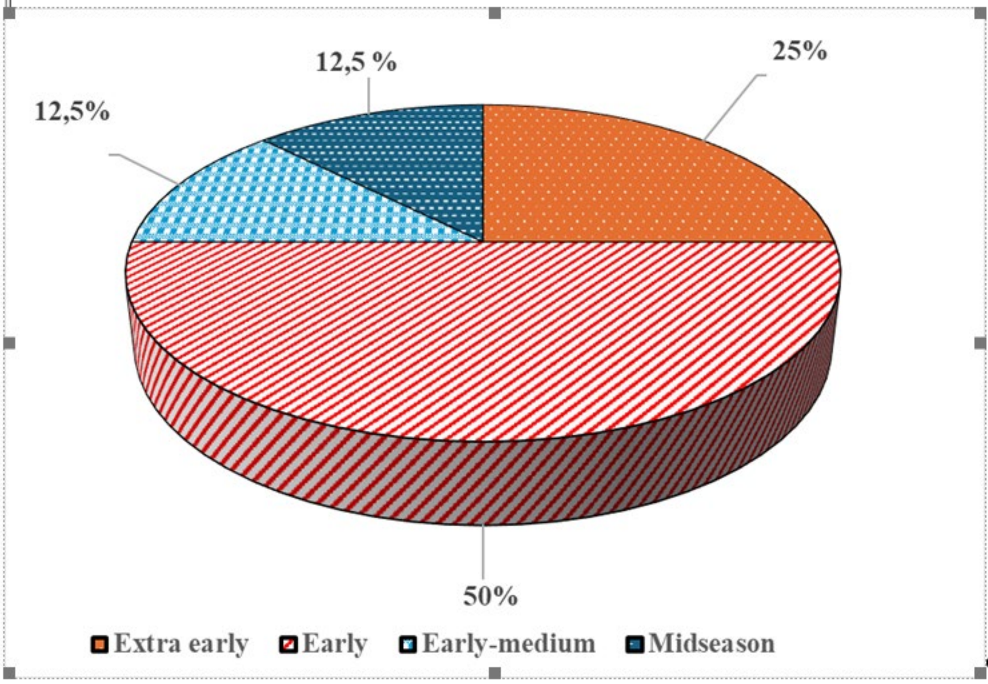


Figure 1. Distribution of Hemerocallis × hybrida varieties by maturity groups

Due to the limited nutrient reserves within a containerized environment, the daylilies required a consistent fertilization regimen. At the onset of the growing season in spring, a urea solution was applied via root drenching at a concentration of 15-20 g per 10 L of water to promote vegetative growth. Prior to anthesis, the plants were treated with potassium sulfate (10-15 g per 10 L of water). This macro-nutrient is essential for optimizing bud initiation, enhancing flowering intensity, and supporting the overall physiological health of the cultivars.

Specific maintenance protocols were implemented throughout the 2024 growing season. To maintain consistent substrate moisture in the containers, irrigation was administered biennially (every other day) during peak summer temperatures. In the spring and autumn, irrigation frequency was reduced to once every 2-3 days in response to declining temperatures and lower evapotranspiration demands. While daylilies exhibit a degree of shade tolerance, optimal floral performance is achieved in full sun; consequently, the plants were positioned to receive a minimum of six hours of direct solar radiation daily to facilitate prolific blooming.

Due to the restricted nutrient volume inherent in containerized systems, the daylilies required a consistent fertilization regimen. At the onset of the spring growing season, a urea solution was administered via root drenching at a concentration of 15-20 g per 10 L of water to promote vegetative development. Prior to anthesis, the plants were treated with potassium sulfate (10-15 g per 10 L of water), as this macronutrient is essential for bud initiation, flowering intensity, and the overall physiological resilience of the cultivars.

Due to the restricted nutrient volume inherent in containerized systems, the daylilies required a consistent fertilization regimen. At the onset of the spring growing season, a urea solution was administered via root drenching at a concentration of 15-20 g per 10 L of water to promote vegetative development. Prior to anthesis, the plants were treated with potassium sulfate (10-15 g per 10 L of water), as this macronutrient is essential for bud initiation, flowering intensity, and the overall physiological resilience of the cultivars.

Morphological characterization and aesthetic evaluation of *Hemerocallis × hybrida* cultivars within the experimental environment. Variety 1: Stella de Oro (Fig. 2).

¶

¶

Figure 2. General view of H. x h. 'Hemerocallis Stella De Oro'

Eight cultivars were selected for a comprehensive analysis of their morphological characteristics and ornamental traits. These varieties are cultivated using containerized production methods (closed root system), utilizing a standardized substrate and maintained under uniform environmental conditions.

This low-growing cultivar reaches a height of up to 40 cm. The blossoms are compact, measuring up to 7 cm in diameter, and exhibit a vibrant yellow hue with smooth-textured petals. The variety possesses high ornamental value, largely due to its extended flowering period of 45-50 days. Its linear, dark green foliage is primarily concentrated in a basal arrangement. Furthermore, this cultivar is characterized by robust resistance to both drought and common pathogens. The striking yellow flowers provide significant visual appeal, while its compact habit makes it an ideal candidate for small-scale landscapes or containerized urban cultivation (Fig. 3).

¶

Figure 3. General view of H. x h. 'Happy Returns'

This cultivar attains a height of up to 50 cm and is distinguished by vibrant yellow blossoms with orange undertones, reaching 9 cm in diameter. The flowering duration spans 40-45 days. Its broad foliage results in a dense, robust habit. Notably, the variety exhibits significant resilience to fluctuating temperature conditions. Its striking yellow-orange floral hues provide exceptional visual impact, allowing it to integrate seamlessly into landscape designs where the rich color contrasts effectively against green foliage or turfgrassVariety 3 ′Chicago Apache′ (Fig. 4).

Figure 4. General view of H. x h. 'Chicago Apache'

This cultivar reaches a height of 60-70 cm and is distinguished by large, scarlet-red blossoms with golden margins, measuring up to 12 cm in diameter. The flowers exhibit a pronounced petal structure, complemented by slightly recurved (curving) foliage. Notably, the variety demonstrates strong resistance to chlorosis and the ability to bloom under low-temperature conditions – a significant advantage for cultivation within the forest-steppe zone.

This variety is characterized by large, uniquely shaped blooms. Its vibrant red-and-gold palette creates a stunning contrast, particularly against lush green foliage. Beyond its visual appeal, this plant is remarkably resilient to environmental stressors. Variety 4 ′Purple de Oro′ (Fig. 5) – Typically reaching a height of 50 cm, this variety boasts a blooming season of 30 to 35 days.

Figure 5. General view of H. x h. 'Purple de Oro'

Variety 5: Catherine Woodbury (Fig. 6).

Figure 6. General view of H. x h. 'Catherine Woodbury'

Reaching a height of 55 cm, this variety offers a prolonged flowering window of 40-45 days. It is distinguished by its pale pink blooms with contrasting white centers, measuring up to 10 cm in diameter. The flowers are elegantly formed, featuring delicate, ruffled petal edges. Complemented by dark green, textured foliage, this plant maintains a medium level of disease resistance [36].

Ideally suited for classic landscape designs, this variety excels where soft tones and a sophisticated aesthetic are paramount. Variety 6: 'Anna Warner' (Fig. 7). Standing at a height of 65-70 cm, this cultivar produces large, vibrant apricot-orange blooms with elegantly ruffled petal margins. The flowers reach a diameter of 12-13 cm, set against a dense clump of broad, dark green foliage. With a generous flowering period of 40-50 days, this variety is characterized by high disease resistance and an ability to withstand brief periods of drought.

Figure 7. General view of H. x h. 'Anna Warner'

This variety is an excellent choice for creating vivid accents within flower beds and mixed borders. Its robust disease resistance and reblooming capacity ensure a lasting decorative impact, making it a prized asset in landscape design. Variety 7: ′Prairie Blue Eyes′ (Fig. 8). Reaching a height of 60-65 cm, this cultivar is noted for its delicate lilac blooms featuring a bright yellow center. The flowers, approximately 10-11 cm in diameter, are framed by narrow, dark green foliage of medium density. With a flowering window of 35-40 days, it is exceptionally winter-hardy and adapts seamlessly to fluctuating climatic conditions.

Figure 8. General view of H. x h. 'Prairie Blue Eyes '

Infusing the garden with a sense of romance and elegance, this variety harmonizes beautifully with white, yellow, and blue blooms. Its versatility makes it ideal for both expansive landscape designs and intimate flower beds. Renowned for its exceptional winter hardiness and pest resistance, it remains a favorite among gardeners. Cultivar 8: ′Apricot Beauty′ (Fig. 9). Reaching a height of 55-60 cm, this plant produces stunning apricot-pink flowers measuring 9-10 cm in diameter. Its elongated, light green leaves feature a prominent texture. The flowering window spans 30-35 days, with the potential for a second bloom in milder climates. It exhibits moderate disease resistance and performs well even in partial shade.

Figure 9. General view of H. x h. 'Apricot Beauty'

The light coloration of the flowers allows for the creation of calm, harmonious floral compositions that look excellent in both landscape and formal styles. Table 2 presents the morphological characteristics of the studied varieties.

Table 2. Morphological characteristics of *Hemerocallis* × *hybrida* varieties

Characteristics	*H.* x *h.* ′Stella De Oro′	*H.* x *h.* ′Happy Returns′	*H.* x *h.* ′Chica go Apache′	*H.* x *h.* ′Purple de Oro′	*H.* x *h.* ′Catherine Woodbu ry′	*H.* x *h.* ′Anna Warner′	*H.* x *h.* ′Prairie Blue Eyes′	*H.* x *h.* ′Apricot Beauty′
Plant height, cm	up to 40	up to 50	up to 60	up to 45	up to 50	up to 70	up to 60	55-60
Bush density	Low, compact	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Number of stems, pcs	up to 3	4-5	up to 3 4	2-3	up to 33	3-4	2-3	2-3
Leaf length, cm	50-60	50-60	65-70	40-50	50-60	60-70	40-50	60-70
Environmental resistance	Highly adaptable to various conditions	Highly resistant to weather changes	Highly resistant to hot climates	Highly adaptable to partial shade	Highly adaptable to various conditions	Highly resistant to wind and rain	Highly adaptable to partial shade	Highly disease-resistant

The provided data offer a comparative assessment of eight *Hemerocallis* (daylily) cultivars: ′Stella De Oro,′ ′Happy Returns′, ′Chicago Apache′, ′Purple de Oro′, ′Catherine Woodbury′, ′Anna Warner′, ′Prairie Blue Eyes′, and ′Apricot Beauty′. Height analysis reveals that the majority of these varieties are medium-sized. Anna Warner is the tallest at 70 cm, whereas ′Stella De Oro′ is the most diminutive, staying under 40 cm. Both ′Chicago Apache′ and ′Prairie Blue Eyes′ maintain a consistent height of approximately 60 cm.

In terms of clump architecture, ′Stella De Oro′ is notably compact with low density, while the remaining varieties exhibit moderate density. Stem counts range from 2 to 5 per plant; ′Happy Returns′ shows the most prolific stem development (4-5 units), while ′Purple de Oro′, ′Prairie Blue Eyes′, and ′Apricot Beauty′ produce the fewest (2-3 units). Leaf length generally spans 40-70 cm, with the maximal values observed in ′Chicago Apache′ and ′Anna Warner′ and the minimal lengths recorded for ′Purple de Oro′ and ′Prairie Blue Eyes′ (40-50 cm).

We also investigated the adaptive properties of the plants. The ′Stella De Oro′ and ′Catherine Woodbury′ varieties were identified as highly adaptable to various growing conditions. The ′Happy Returns′ variety demonstrates high resistance to weather changes, ′Chicago Apache′ is the most heat-tolerant, and ′Anna Warner′ stands out for its resistance to mechanical damage from wind and rain. The ′Purple de Oro′ and ′Prairie Blue Eyes′ varieties are the most suitable for cultivation in partial shade conditions. The ′Apricot Beauty′ variety was noted as being highly disease-resistant. Based on the tabular data, it can be concluded that each variety possesses a unique combination of ornamental and biological traits. ′Stella De Oro′ is the best choice for border plantings due to its compactness, while it is advisable to use ′Anna Warner′ and ′Chicago Apache′ as tall accent elements in the landscape due to their high resistance to unfavorable weather conditions. Overall, all studied varieties of *Hemerocallis* × *hybrida* possess high ornamental value. A comparative description of the flower's ornamental qualities is provided in Table 3.

Table 3. Comparative characteristics of the flower's ornamental properties of *Hemerocallis* × *hybrida* varieties.

Characteristics	*H.* x *h.* ′Stella De Oro′	*H.* x *h.* ′Happy Returns′	*H.* x *h.* ′Chicag o Apache′	*H.* x *h.* ′Purple de Oro′	*H.* x *h.* ′Catheri ne Woodbu ry′	*H.* x *h.* ′Anna Warner′	*H.* x *h.* ′Prairie Blue Eyes′	*H.* x *h.* ′Apricot Beauty′
Flower size, cm	5-6	8-9	up to 12	up to 8	up to 10	up to 13	9-10	up to 12
Flower shape	Round	Round with ruffled petals	Round with wavy petals	Semi-round with rounded petals	Round with wavy petals	Semi-round with wavy petals	Star-shaped with wavy edges	Star-shaped with ruffled petals
Flower color	Bright yellow	Lemon-orange	Red with a golden center	Lavender-purple	Light pink with a white center	Bright orange with a golden tint	Lilac with a yellow center	Orange-pink, with a yellow gradient towards the center

The diverse color palette of these daylilies allows for precise selection tailored to specific landscape requirements. With blooming periods exceeding one month, these varieties guarantee a sustained ornamental impact. Furthermore, the variation in floral and foliage morphology gives each cultivar a distinct identity, while the range of heights facilitates the creation of multi-dimensional, dynamic compositions.

Among the studied group, ′Anna Warner′ produces the largest blooms (up to 13 cm), establishing it as a natural focal point. In contrast, ′Stella De Oro′ features the most petite flowers (5-6 cm), which are approximately half the size of the larger-flowered varieties such as ′Chicago Apache′ and ′Apricot Beauty′ (up to 12 cm).

While most of the evaluated cultivars feature round or semi-round bases, they exhibit significant variation in edge texture. Notably, ′Happy Returns′ and ′Apricot Beauty′ are distinguished by pronounced ruffling, which enhances floral volume. Conversely, ′Prairie Blue Eyes′ and ′Apricot Beauty′ possess a unique star-shaped morphology, providing a sharp contrast to the conventional rounded forms of other varieties. The color palette is primarily composed of warm, solar tones such as yellow and orange, though contrasting hues are also represented. ′Chicago Apache displays the highest saturation with its deep red tones, while ′Catherine Woodbury′ offers a delicate pale pink. The cool end of the spectrum is represented by the lilac and lavender hues of ′Prairie Blue Eyes′ and ′Purple de Oro′, respectively.

In contrast to the monochromatic palette of ′Stella De Oro′, most of the other cultivars exhibit complex color structures. ′Apricot Beauty′ is particularly noteworthy for its seamless yellow gradient, while varieties with contrasting centers – such as ′Chicago Apache′, ′Catherine Woodbury′, and ′Prairie Blue Eyes′ – offer a sense of visual depth.

The diversity of floral forms, ranging from simple rounded shapes to sophisticated star-like profiles, combined with an extensive color spectrum, enables the design of dynamic garden arrangements with varied heights and textures. The findings indicate that all studied *Hemerocallis* × *hybrida* varieties possess significant ornamental potential for diverse landscape applications, though the choice of a specific cultivar should be guided by site-specific requirements and environmental conditions

The role of *Hemerocallis* × *hybrida* in ornamental gardening. Selecting *Hemerocallis* × *hybrida* cultivars is a fundamental element in the design of ornamental landscapes. These plants are prized for their aesthetic appeal, extended flowering duration, and diversity in morphology and color. To maximize their effectiveness, it is crucial to account for their morphological traits, environmental requirements, and synergistic potential with companion plants [35]. Accurate variety selection necessitates a thorough understanding of specific flowering windows, as these timelines vary across cultivars. Consequently, this factor is a vital consideration in site planning. The flowering intensity of these daylilies is detailed in Table 4.

Table 4. Comparison of blooming intensity among *Hemerocallis* × *hybrida* varieties

Observation date	*H.* x *h.* ′Stella De Oro′; %	*H.* x *h.* ′Happy Returns′; %	*H.* x *h.* ′Chicago Apache′; %	*H.* x *h.* ′Purple de Oro′; %	*H.* x *h.* ′Catherine Woodbury′; %	*H.* x *h.* ′Anna Warner′; %	*H.* x *h.* ′Prairie Blue Eyes′; %	*H.* x *h.* ′Apricot Beauty′; %
15.06	5	10	5	0	0	0	15	0
01.07	30	40	30	15	0	20	55	0
15.07	55	50	50	40	5	50	30	20
31.07	10	0	15	45	25	30	0	60
15.08	0	0	0	0	70	0	0	20

When planning a daylily planting site, consider the existing seasonal interest. If your garden already features spring, late summer, or early autumn blooms, varieties like ′Happy Returns′ and ′Prairie Blue Eyes′ are ideal for filling the early summer gap. ′Prairie Blue Eyes′, for instance, begins flowering in early June and remains decorative until late July, reaching its peak intensity around July 1st.

Conversely, if the site lacks mid-summer color, ′Anna Warner′, ′Chicago Apache′, ′Stella De Oro′, and ′Purple de Oro′ are the most suitable choices. These varieties peak around July 15th with a blooming intensity of 50-55%, lasting through the end of the month. Meanwhile, ′Catherine Woodbury′ and ′Apricot Beauty′ provide their most vibrant displays in the latter half of summer, though their flowering windows are notably brief.

The significance of *Hemerocallis × hybrida* in ornamental horticulture stems from its versatile application in various planting schemes, including mixed borders, flower ribbons (rabatki), traditional beds, specimen plantings (solitaires), and edging. This utility is enhanced by a vast diversity in floral morphology, color, and size, enabling the creation of bespoke garden compositions. Beyond their aesthetic appeal, these hybrids are noted for their robust resistance to environmental stressors, pathogens, and pests. They are notably drought-tolerant and winter-hardy; furthermore, their resilience to air pollution makes them an excellent choice for urban landscaping.

In practice, daylilies serve multiple roles. For border applications, 'Stella De Oro' and 'Purple de Oro' are particularly effective due to their compact growth habit and extended flowering seasons. These varieties pair harmoniously with low-growing annuals like verbena or petunia (Fig. 10) [35].

Figure 10. Use of Hemerocallis × hybrida in border plantings

For specimen (solitary) plantings, the Prairie Blue Eyes, Anna Warner, and Chicago Apache varieties can be used, as they draw focus through their vibrant floral coloring (Fig. 11).

Figure 11. Use of Hemerocallis × hybrida in specimen (solitary) plantings

In mixed borders (mixborders), varieties such as ′Apricot Beauty′, ′Chicago Apache′, ′Happy Returns′, and ′Catherine Woodbury′ can be used, as they pair well with other perennials, annuals, and ornamental grasses (Fig. 12).

Figure 12. Use of Hemerocallis × hybrida in mixed borders

In group plantings, the ′Stella De Oro′, ′Happy Returns′, ′Anna Warner′, ′Prairie Blue Eyes′, and ′Catherine Woodbury′ varieties pair effectively with coniferous shrubs, creating a striking accent against their deep green foliage. They also combine beautifully with other perennials that have similar flower colors to create a delicate and harmonious composition (Fig. 13).

Figure 13. Use of Hemerocallis × hybrida in group plantings

Varieties such as 'Stella De Oro' and 'Purple de Oro' are used for container planting and are placed on patios, balconies, or terraces. Their height does not exceed 45 cm, so they do not require much space on the site (Fig. 14).

Figure 14. Use of Hemerocallis × hybrida in container plantings

Daylilies offer a highly naturalistic aesthetic when positioned near water features, enhancing the organic feel of a landscape. For ponds and streams, varieties that tolerate higher moisture levels – such as ′Stella De Oro′, ′Purple de Oro′, and ′Prairie Blue Eyes′ – are ideal choices (Fig. 15). Whether used as standalone specimens, in mass groupings, or as border plantings, they help stabilize shorelines and seamlessly integrate artificial water bodies into the broader garden concept. These varieties harmonize beautifully with moisture-loving companions like ferns, hostas, and reeds [48].

Figure 15. Use of Hemerocallis × hybrida in plantings near water bodies

In conclusion, *Hemerocallis × hybrida* cultivars represent a highly valuable asset to ornamental horticulture, primarily due to their extended flowering duration. By strategically selecting specific varieties, a continuous succession of blooms can be maintained throughout the entire summer season. Their diverse range of plant heights and floral palettes allows for the creation of multifaceted combinations – from mixed borders and edging to specimen and group plantings, and even container gardening. This adaptability makes them exceptionally versatile for both urban greening and private landscape projects.

The application of *Hemerocallis* × *hybrida* in contemporary floristry and interior phytodesign

Recent shifts in floral art reflect a departure from standardized industrial crops in favor of garden-style flowers, with hybrid daylilies (*Hemerocallis* × *hybrida*) occupying a prominent role. Their extensive color palette – spanning from pastel creams to deep purples and near-black hues – enables the creation of sophisticated monochromatic and high-contrast compositions that align with contemporary aesthetic trends [49]. A defining characteristic of the daylily is its ephemerality; while the short lifespan of individual blooms was once seen as a commercial drawback, modern floral studios now embrace it as a symbol of 'fleeting beauty' and ecological authenticity. Research indicates that daylilies are particularly effective in bridal bouquets and event decor, as they maintain turgor for 12-18 hours without supplemental hydration – a vital trait for short-term festivities [50].

In commercial floristry, prioritizing cultivars with multi-flowered scapes is essential. Modern tetraploid hybrids can sequentially open their buds on a single cut stem over 5-7 days, provided stable temperatures are maintained and professional floral preservatives are utilized [35]. The specialized preparation techniques implemented at ensure the production of premium-grade cut flowers, where each TOV SP «Demetra» subsequent bud retains high ornamental value.

Another promising application is the use of flowering daylilies in containers as components of interior phytodesign and terrace styling. Container-based cultivation enables the seamless integration of daylilies into vertical gardens and modular living walls.

Figure 16. Photo of a blooming daylily in a container for interior phytodesign

Recent shifts in floral art reflect a departure from standardized industrial crops in favor of garden-style flowers, with hybrid daylilies (*Hemerocallis* × *hybrida*) occupying a prominent role. Their extensive color palette – spanning from pastel creams to deep purples and near-black hues – enables the creation of sophisticated monochromatic and high-contrast compositions that align with contemporary aesthetic trends [49]. A defining characteristic of the daylily is its ephemerality; while the short lifespan of individual blooms was once seen as a commercial drawback, modern floral studios now embrace it as a symbol of fleeting beauty and ecological authenticity. Research indicates that daylilies are particularly effective in bridal bouquets and event decor, as they maintain turgor for 12-18 hours without supplemental hydration – a vital trait for short-term festivities [35, 49, 50].

For floristry, the strength of the scape and the resistance of the petals to mechanical damage are critical indicators. Varieties with a high wax content in the petal epidermis are most suitable for transportation and use in complex floral structures [35, 50].

Thus, *Hemerocallis* × *hybrida* is a versatile material for modern floristry, enabling the implementation of both short-term decorative tasks (cut flowers, boutonnieres) and long-term projects within interior phytodesign systems. Further study of the cultivar assortment at TOV SP «Demetra» will allow for the identification of a group of varieties most adapted for floristic use, based on indicators of flower lifespan and scape strength.

Conclusions and recommendations for production

1.Based on original phenological observations, it has been established that the container cultivation technology of *Hemerocallis* × *hybrida* in the conditions of the Forest-Steppe zone of Ukraine promotes an early start of the growing season; specifically, for the 'Prairie Blue Eyes' variety, this begins on March 17.

2.As a result of comparing 8 varieties based on their decorative properties, 4 can be identified as suitable for continuous summer blooming: ′Prairie Blue Eyes′, ′Happy Returns′, ′Chicago Apache′, and 'Stella De Oro′.

3.Phenological observations have confirmed that varieties with an earlier start to their growing season possess a longer flowering period compared to those in which the growing season begins later.

4.Based on the results of categorizing varieties by the onset of specific phenological phases, the plants have been classified into the following groups: very early, early, mid-early, and mid-season.

5.It has been proven that the ′Stella De Oro′, ′Happy Returns′, and ′Chicago Apache′ varieties performed best under container cultivation. With this cultivation technology, these varieties demonstrate high decorative value, vibrant blooming, and resilience to climatic changes.

6.When landscaping a specific site, it is necessary to consider the plant dimensions, the type of plant composition, and its functional purpose. Therefore, for ribbon beds (*rabatkas*) and borders, I recommend using the ′Stella De Oro′ and ′Happy Returns′ varieties, while ′Anna Warner′ and ′Chicago Apache′ are better suited as specimen plants.

7.In the conditions of the Forest-Steppe zone of Ukraine (eastern part of the Kyiv region), the most promising varieties for container cultivation technology are: ′Prairie Blue Eyes′, ′Happy Returns′, and ′Stella De Oro′.

8.To ensure continuous blooming on a site, the following varieties can be planted: Happy Returns and Prairie Blue Eyes (early flowering period), Anna Warner and Purple de Oro (mid-season flowering period), and Catherine Woodbury (mid-season flowering period).

REFERENCES

1. Kuznetsov S.I., Levon F.M., Pylypchuk V.V., (2023) The current state and development prospects of green infrastructure in Ukrainian cities in the context of global climate change, *Scientific Reports of NUBiP of Ukraine*. N.2, 102p.
2. Tkachuk O.P., Pantsyreva H.V., (2021) Adaptive potential of ornamental plants und Pylypenko O. I., Pylypenko O. I.,er conditions of moisture deficiency and temperature stress in urban environments, *Agriculture and Forestry,* N.22, P.89-103.
3. Bereziuk S.V., (2021) Breeding achievements and innovative propagation technologies of *Hemerocallis* × *hybrida* in Ukraine, *Scientific Papers of the Institute of Bioenergy Crops,* N.29, P.45-52.
4. Kolesnichenko O.V., Slyvka T.M., (2024) Daylily culture (*Hemerocallis* L.) in modern landscape design: biodiversity and decorative properties, *Landscape Architecture and Design,,,* N.1(18). P.45-56.
5. Havryliuk V. A., Trofymenko O. V., (2023) Global breeding trends of *Hemerocallis* × *hybrida*: from diploid to tetraploid forms, *Bulletin of Agricultural Science,* N.12 (849). P112-120.
6. Pylypenko O. I., (2022) The use of miniature and giant daylily forms in the creation of rock gardens and complex mixed borders, *Ornamental Gardening and Phytodesign,* Vol.4, N.29, P.33-41.
7. Schiefelbein K., Weber J., (2023) Advances in Hybridization of Perennials: The Case of *Hemerocallis*, *Journal of Horticultural Science & Biotechnology*, Vol.98, N.5, P.502-515.
8. Trofymenko O.V., Havryliuk V.A., (2023) Assessment of groundcover properties of *Hemerocallis* × *hybrida* under conditions of intensive exploitation of urban sites*, Bulletin of Agricultural Science,* N. 5(842), P. 67-75.
9. Shevchenko A.M., (2021) The concept of «Low-maintenance landscape» in modern urban greening of Ukraine, *Modern Technologies and Methods in Architecture and Design,* Vol.15, P. 201-210.
10. Dunnett N., (2022) Naturalistic Planting Design: The New Perennial Movement. 2nd Edition. London: Filbert Press, 256 p.
11. Kliuvaka M.O., Lozynskyi M.V., Fedorchuk S.V., (2024) Biotechnological aspects of in vitro propagation of ornamental plants: current state and prospects, *Agricultural innovations*, N.23, P.44-52.

12. Podhaietskyi A.A., Matskevych V. V., Podhaietskyi A.An., (2018) Specifics of micropropagation of plant species: a monograph, Bila Tserkva: BNAU, 209 c.
13. Melnyk V. I., Romanenko O. V., (2022) Automation of drip irrigation and fertigation systems in indoor and outdoor ornamental nurseries*, Energy and Automation,* Vol.4(58), P.132-141.
14. Smith J. R., Tanaka H., (2024) Advancements in Plant Tissue Culture for the Ornamental Industry: A Global Perspective, *Journal of Horticultural Science and Biotechnology*, Vol.99, (2), P.156-172.
15. Luo X., Zhang Y., (2023) Smart Irrigation and Fertigation Management in Specialized Nursery Production, *Agricultural Water Management*, Vol.281, P.108-124.
16. Tkachenko O.V., Melnyk H.I., (2024) Impact of continuous bloom landscape compositions on the psycho-emotional state of the urban population, *Psychology and Society,* N.1 (95). P.134-145.
17. Kolesnichenko O. V., Slyvka T. M., (2023) Formation of recreational attractiveness of park areas by means of modern phytodesign*, Landscape Architecture and Design,* N.3 (16). P.22-31.
18. Shevchenko A. M., (2022) Economic efficiency of using perennial herbaceous plants in urban greening: a comparative analysis, *Economy and Management of the Agro-Industrial Complex,* Vol.2 (171). P.102-111.
19. Bondar S. P., Oleksiienko V. V., (2021) The duration of cultivation for *Hemerocallis* × *hybrida* cultivars in one location without loss of ornamental qualities. Ornamental Gardening and Nursery Production, N.5 (28), P.47-55.
20. Gao T., Zhang T., (2023) The influence of flower color and floral scent on psychological well-being in urban green spaces. *Urban Forestry and Urban Greening*, Vol.82, P.127-141.
21. Mullins K., O'Brien L., (2022) Sustainable Landscapes: Long-term Maintenance and Economic Viability of Perennial Plantings, *Journal of Environmental Management*, Vol.304, P.114-128.
22. Kolesnichenko O.V., Slyvka T.M., (2024) Current state and prospects for expanding the assortment of the genus *Hemerocallis* L. in landscape architecture objects of Ukraine, *Landscape Architecture and Design*, N.1 (18), P..22-35.
23. Havryliuk V.A., Trofymenko O.V., (2023) Cultivar resources of *Hemerocallis* × *hybrida* in domestic nurseries: a critical review and ways for Havryliuk V. A., Trofymenko O. V.,24. Shevchenko A. M., (2022) Challenges of implementing innovative phytodesign concepts under conditions of a limited planting material market, Modern *Technologies and Methods in Architecture and Design,* Vol.18, C.115-124.
24. Kozlovska H., Shumylo H., (2021) Assessment of the Adaptive Potential of New *Hemerocallis* Cultivars for Urban Landscapes. *Environmental Sciences and Ecology*, Vol.5, N.2, P.102-114.
25. Havryliuk V.A., Trofymenko O.V., (2024) Potential of tetraploid *Hemerocallis* × *hybrida* cultivars of foreign selection under the conditions of climate change in Ukraine. *Bulletin of Agricultural Science.* Vol.3(852), C.54-62.
26. Tkachuk O.P., Pantsyreva H.V., (2022) Physiological responses of introduced daylily cultivars to extreme summer droughts: resistance mechanisms and risks. *Agriculture and Forestry,* N.25, P.112-125.
27. Kolesnichenko O.V., Slyvka T.M., (2024) Development of adaptive technological charts for ornamental crop cultivation as a factor in minimizing plant loss in nurseries, *Landscape Architecture and Design,* N.2 (19), P.36-45.
28. Kozlovska H., Shumylo H., (2021) Winter Hardiness and Drought Resistance of Tetraploid *Hemerocallis* Cultivars in Eastern Europe. *Environmental Sciences and Ecology*, Vol.5, N.4, P.158-170.
29. Schiefelbein K., (2023) Physiological Challenges of Tetraploid Perennials in Variable Climates: From Greenhouse to Field. *Journal of Horticultural Research*, 2023, Vol.31, N.1, P.77-89.
30. Kolesnichenko O.V., Slyvka T.M., Kushnir S.A., (2021) Current state and prospects for using ornamental herbaceous perennials in mobile landscaping, *Scientific Reports of NUBiP of Ukraine,* N.3(91). P.1-16.
31. Havryliuk V.A., Trofymenko O.V., (2023) The influence of substrate composition and root zone volume on the ornamental qualities of *Hemerocallis* × *hybrida* under conditions of limited soil space. *Bulletin of Agricultural Science.* Vol.10(847), P.41-50.
32. Pantsyreva H.V. Formation of ornamental value in flower crops under the influence of growth stimulants. *Agriculture and Forestry,* 2021. N.21. P.134-145.
33. Nowak J.S., Nowak K**.** (2022). Effect of selected growth regulators on the growth and flowering of some ornamental perennials. *Journal of Horticultural Research*, Vol. 30, Issue 1, P.101-110.
34. Trofymenko O.V., (2021) Cultivar assessment of Hemerocallis × hybrida based on ornamental, economic, and biological traits under the conditions of the Ukrainian Forest-Steppe. *Bulletin of Poltava State Agricultural Academy,* N. 2. P. 118-126.
35. Kosyk O.I., Horupakha V.H., Humeniuk M.O., (2020) The use of container gardening in the urban environment. Design Theory and Practice: A Collection of Scientific Papers. K.: NAU, Vol.20, P.58-65.
36. Marchyshyn S. M., Zarichanska O. V., (2016) Phytochemical, morphological, and anatomi anatomical study of plants of the genus Daylily (*Hemerocallis* L.) Methodological recommendations. Ternopsl: Ukrmedknyha, 37 p.
37. Humeniuk A. I., Matviienko O. S., (2014) Floriculture with Fundamentals of Landscape Design, Kyiv. Fitosotsiotsentr, 336 c.
38. Methods of conducting examination of ornamental plant varieties for suitability for dissemination in Ukraine: Ukrainian Institute for Plant Variety Examination, (2021), Kyiv, 142 p.

39. Tkachyk S. O., Prysiazhniuk O. I., Leshchuk N. V., (2017) Methods of conducting qualification examination of plant varieties for suitability for dissemination in Ukraine. General part: 4th edition, revised and updated, Vinnytsia: FOP Korzun D. Yu., 119 p.
40. Havryliuk V. A., Trofymenko O. V., (2024) Peculiarities of growth and development of *Hemerocallis × hybrida* under open ground conditions in the Ukrainian Forest-Steppe. Vol.4(853), P.44-52.
41. Kolesnichenko O. V., Slyvka T. M., (2024) Optimization of parameters for container cultivation of ornamental perennials in mobile gardens, Landscape Architecture and Design, N.1(18). P.68-77.
42. Buyun L. I., Cherevchenko T. M., Kovalska L. A. (2018) Ecological aspects of ornamental plant cultivation under glass, Plant introduction, N. 4, P.62-75.
43. Melnyk V. I., Romanenko O. V., (2024) Energy-efficient technologies for creating and maintaining microclimate in modern greenhouse complexes, *Energy and Automation,* Vol.1(63), P.112-125.
44. Tkachuk O. P., Pancyreeva H. V., (2022) Agrotechnical requirements for substrates for perennial herbaceous plants in protected and open ground. *Agriculture and Forestry,* N.23, P.130-142.
45. Pryiula V.M., Konyshchuk V.V., (2022) Hydroponics as an innovative technology in modern crop production, Agroecological Journal, 2022, N.3. P.114-122.
46. Photo: Use of Hemerocallis x hybrsda in plantings near water bodies. [Electronsc resource]. Access mode: https://sad.ukr.bio/ua/articles/4746/
47. Pantsyreva H.V. (2021) Formation of ornamental qualities in floral crops under the influence of growth stimulants. *Agriculture and Forestry*. N. 21, C.134-145.
48. Havryliuk V. O., (2022) Biomorphological features of *Hemerocallis × hybrida* cultivars under conditions of introduction, *Agrobiology,* N.1, P.44-52.

ORGANIZATION AND IMPROVEMENT OF THE FIRE PROTECTION SYSTEM FOR FOREST ECOSYSTEMS: THE CASE OF THE STATE ENTERPRISE «KRASNOPILSKY AGROLISGOSP»

Horbas Serhii
Candidate of Agricultural Sciences, Associate Professor of the Department of Horticulture and Forestry, Sumy National Agrarian University, Ukraine
ORCID ID: 0000–0003–3768–8833

Kytaihora Anton
PhD Student, Department of Horticulture and Forestry, Assistant, Department of Horticulture and Forestry, Sumy National Agrarian University, Ukraine
ORCID ID: 0009–0008–0459–3508

Introduction

Forest ecosystems are one of the most important components of the natural environment, ensuring the maintenance of ecological balance and playing a key role in supporting the sustainable development of society. They perform a wide range of functions, including climate regulation, soil protection, water conservation, recreational, and resource–related functions. Forests contribute to biodiversity conservation, accumulate carbon, reduce the negative impact of climate change, and constitute an important element of the economic development of regions.

Under current conditions, the importance of forest resources is growing significantly; however, at the same time, the influence of negative factors on their condition is also increasing. One of the most serious threats to forest ecosystems is forest fires, which lead to significant ecological, economic, and social losses. As a result of fires, forest plantations are destroyed, soils degrade, natural ecosystems are disrupted, and biodiversity decreases. In addition, fires negatively affect air quality and pose a threat to human life and health.

The relevance of the forest fire problem is determined by modern global processes, in particular climate change, which is manifested in rising air temperatures, reduced precipitation, and an increase in the duration of dry periods. Such conditions contribute to a higher level of fire hazard and complicate fire suppression processes. A significant influence is also exerted by the anthropogenic factor, which is manifested in non–compliance with fire safety regulations, economic activity, and recreational pressure on forests.

For Ukraine, the problem of forest fires is especially relevant due to the combination of natural and anthropogenic factors, as well as the impact of current socio–economic and military conditions. The consequences of hostilities, the presence of explosive hazards, limited access to certain territories, and damage to infrastructure significantly complicate the organization of effective forest fire protection.

Under these conditions, the need to improve the forest fire protection system becomes particularly important. This system should be based on an integrated approach and combine preventive, organizational, and technical measures. An effective protection system involves the timely detection of fire outbreaks, forecasting their development, prompt response, and minimization of negative consequences.

The object of the study is the processes of occurrence, development, and spread of forest fires within forest ecosystems.

The subject of the study is the organization of the forest fire protection system in the activities of the State Enterprise "Krasnopilskyi Agrolisgosp".

The aim of the study is the scientific substantiation and development of effective organizational and technical measures to improve the level of fire protection of forest areas within a specific forestry enterprise.

To achieve this aim, the following research objectives were defined:

– to investigate the peculiarities of the occurrence and development of forest fires;
– to analyze the natural and economic conditions of forest stand functioning;
– to assess the effectiveness of the existing fire monitoring and detection system;
– to analyze fire protection measures;
– to develop practical recommendations for improving the forest protection system.

The methodological basis of the study is the application of a set of general scientific methods, including analysis, synthesis, generalization, comparison, a systems approach, as well as elements of statistical analysis and observation. The use of these methods ensured a comprehensive study of the problem and made it possible to obtain well–grounded results.

The scientific novelty of the study lies in improving approaches to the organization of forest fire protection, taking into account modern challenges, including climate change and restrictions related to martial law.

The practical significance of the obtained results lies in the possibility of their application in the activities of forestry enterprises, public administration bodies, and emergency rescue services in order to increase the effectiveness of measures aimed at the prevention and elimination of forest fires.

The structure of the study is determined by its aim and objectives and includes an introduction, the main part, conclusions, and a list of references. The study consistently examines the theoretical foundations of the problem, analyzes the practical state of forest fire protection, and proposes directions for its improvement.

Peculiarities of the occurrence of forest fires and firefighting technologies. A large part of the territory of Ukraine is covered with forests, which are a true national treasure and a source of pride for our people. Forests require careful protection, since their negligent use may lead to destructive consequences. Forest fires are especially dangerous, as they represent one of the most serious environmental threats capable of disrupting the natural balance and causing damage to entire forest areas. Climate change and the growing anthropogenic impact contribute to the increasing frequency with which such fires affect large territories.

In Ukraine, the situation is further complicated by the consequences of hostilities, which increase the likelihood of such disasters. During forest fires, not only are enormous numbers of trees destroyed, but many animals and birds also perish, buildings are damaged, and tremendous material losses occur.

The main hazardous factors of such fires are high temperature, which causes ignition of everything within the combustion zone; thermal radiation, due to which combustible materials may ignite even beyond the fire center; and heavy smoke, which irritates the respiratory tract, negatively affects the psychological state of people, and in severe cases may cause carbon monoxide poisoning.In addition, smoke reduces visibility and complicates the movement of vehicles as well as the work of rescue services.

Despite preventive forest protection measures, the summer months still create favorable conditions for the occurrence and spread of fires. Statistics indicate that every year in Ukraine from 10 to 15 thousand forest fires are recorded over an area exceeding 500 hectares. The main causes of forest fire occurrence include the human factor, which accounts for 60% of cases, negligence of organizations and expeditions (19.7%), logging activities (3.5%), agricultural burning (6.7%), natural factors such as lightning (8.1%), and other causes (2%). Thus, in nearly 90% of cases, the occurrence of forest fires is associated with careless human handling of fire.Thus, in 90% of cases, responsibility for forest fires lies with humans and their careless handling of fire.

An important aspect of forest fire research is also the analysis of the conditions of their spread and the dynamics of their development. A fire in a forest environment is a complex physicochemical process that depends on many variables, among which weather conditions, the structure of vegetation cover, and terrain play a key role.

One of the determining factors is wind, which not only contributes to the spread of flames but also determines the direction of fire movement. In strong winds, the rate of fire spread may increase several times, which significantly complicates the process of localization. At the same time, a change in wind direction may create unpredictable situations that pose a threat to rescuers.

The composition and structure of forest stands are also of great importance. Young coniferous forests, especially pine forests, are characterized by high fire hazard due to the presence of resinous substances that ignite easily. Deciduous forests, by contrast, have lower combustibility; however, when a significant amount of dry vegetation accumulates, they may also become a source of intense burning.

Special attention should be paid to forest litter, which consists of dry leaves, needles, branches, and organic residues. It is often the primary source of ignition and contributes to the transition of a ground fire into a crown fire. The accumulation of a large amount of combustible material increases the risk of rapid fire development even in the presence of minor ignition sources.

Terrain also significantly affects the nature of fire spread. On slopes, fire spreads uphill more quickly, which is explained by the rise of hot air and the preheating of vegetation. In lowlands, by contrast, fires may develop more slowly but are often accompanied by heavy smoke.

Thus, taking into account the complex of natural and anthropogenic factors makes it possible to assess fire hazard more accurately and to develop effective measures aimed at reducing it.

Additionally, it should be taken into account that the intensity and rate of spread of forest fires largely depend on the moisture content of combustible materials. When the moisture content of forest litter and vegetation is low, even a minor ignition source may lead to a large–scale fire. During periods of prolonged drought, the risk of fire occurrence increases several times, which requires strengthened monitoring of the condition of forest areas.

An important factor is also the seasonality of fire occurrence. The largest number of ignitions is observed in the spring and summer periods, when dry vegetation accumulates and weather conditions are characterized by high temperatures and low humidity. At this time, enhanced fire safety measures and restrictions on access to forest territories should be introduced.

The level of economic development of the territory also has a significant influence on the occurrence of fires. In particular, the presence of forest roads, recreation areas, leisure sites, and forestry operations increases the probability of fire outbreaks due to the human factor. In this regard, the organization of control over compliance with fire safety rules and the implementation of preventive work among the population become especially important. Equally important is consideration of the spatial distribution of fire hazard. Different forest areas have different levels of fire risk depending on the type of vegetation, the age of plantations, stand density, and the presence of combustible materials. This determines the need for zoning the territory according to the level of fire hazard and for a differentiated approach to the organization of protection measures.

Modern scientific studies indicate the expediency of using fire hazard indices that take into account a complex of meteorological and ecological indicators. Such indices make it possible to predict the probability of fire occurrence and to take preventive measures in a timely manner.

In addition, it is important to consider the possibility of the secondary consequences of forest fires, which are manifested in the form of soil erosion, disruption of the water regime of territories, a decrease in forest productivity, and changes in species composition. In the long term, this may lead to ecosystem degradation and the loss of their ecological functions.Thus, the problem of forest fires requires an integrated approach that includes not only the analysis of their causes, but also the assessment of spread conditions, forecasting of fire development, and the development of effective preventive measures. The combination of scientific approaches with practical measures will make it possible to significantly improve the level of protection of forest ecosystems and minimize the negative consequences of fires.

The following types of fires are distinguished:

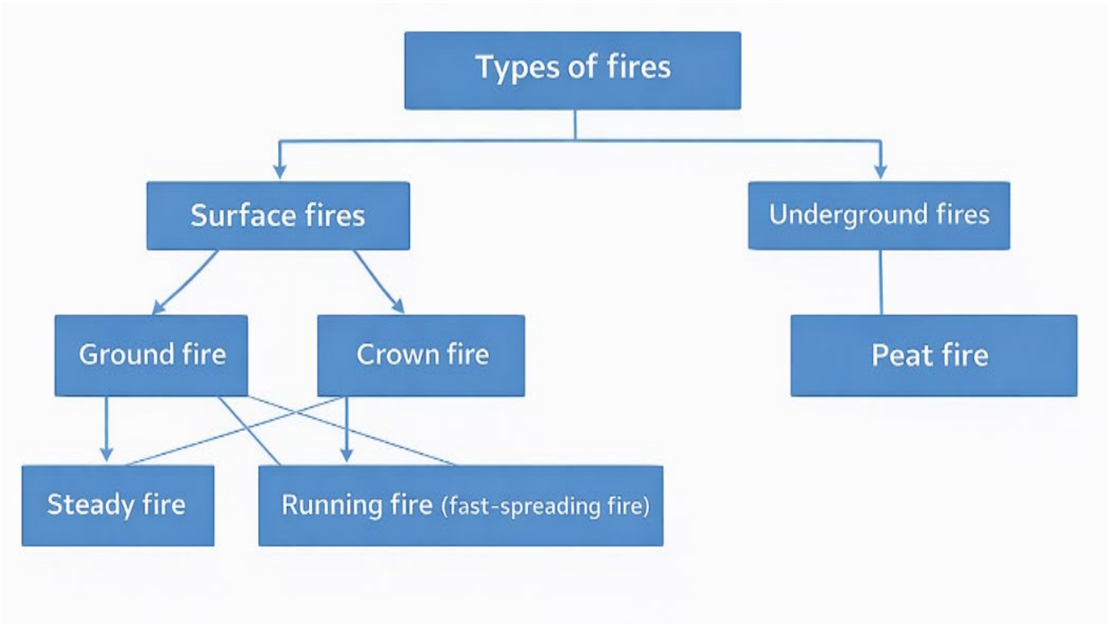


Figure 1. Types of fires

Table 1. Characteristics of forest fire types

No.	Type of forest fire	Characteristics
1	**Surface fire**	A fire that spreads through the forest floor fuel layer, including lichens, mosses, forest litter, grasses, shrubs, woody debris, windthrown material, and logging residues. It may also affect the lower vegetation layer, including young growth and underbrush (see Fig. 1.2).
2	**Fast–spreading surface fire**	A surface fire with a frontal edge moving at a speed of more than 0.5 m/min and characterized by intensive flaming combustion. Such fires cause significant burning of the forest floor cover.
3	**Crown fire**	A fire that spreads through the crowns of forest stands. In this case, a surface fire often acts as a component of the crown fire (see Fig. 1.3).
4	**Sustained crown fire**	A crown fire with an intensity of up to 4 km/h that affects tree crowns and is accompanied by stable surface burning. As a result, almost the entire area is burned out, and only charred tree trunks remain.
5	**Underground fire**	A fire associated with the smoldering of the peat soil layer without open flame (see Fig. 1.4).
6	**Slow–spreading surface fire**	A surface fire with a frontal edge moving at a speed of less than 0.5 m/min, in which combustion occurs mainly in a flameless form, that is, through the smoldering of surface combustible materials.
7	**Running crown fire**	A crown fire spreading at a speed of up to 4 km/h, affecting both tree crowns and the front of a sustained surface fire. As a result, the area may burn out almost completely, leaving only charred remains of tree trunks.

It should be noted that almost any forest fire at the initial stage of its development takes the form of a surface fire and, under appropriate conditions, may develop into a crown fire or an underground fire.

Figure 2. Surface fire

The appearance of surface and crown fires is schematically illustrated in Fig. 2 and Fig. 3, respectively.

Figure 3. Crown fires

The appearance of an underground (peat) fire is schematically illustrated in Fig. 4.

Figure 4. Peatland burning

The occurrence and development of forest fires depend significantly on weather conditions. According to weather conditions, the following fire danger classes are distinguished: no fire danger, moderate fire danger, high fire danger, and extreme fire danger.

The detection of forest fires is critically important for preventing their further spread and reducing their consequences. A rapid response to ignition makes it possible to minimize potential damage and human casualties, as well as to preserve natural resources. However, modern methods of forest fire detection and forecasting are still not sufficiently effective.

Forest fires are a complex process that may break out in any part of a forest. Therefore, it is necessary to have a variety of effective monitoring and detection tools in order to ensure a prompt response. At present, the main methods of forest fire detection are ground–based observation, observation from fire towers, aerial patrols, and satellite observation.

Forest monitoring is a systematic observation of forest conditions aimed at ensuring the effective management and protection of natural resources. This process contributes to the assessment of changes in forest ecosystems, the identification of problems, and the development of strategies to overcome them. Traditional forest monitoring methods are an important means of determining the extent of forest areas, their structure, and species composition. Table 2.

The collection and analysis of meteorological data constitute an important component of traditional monitoring methods that influence the condition and dynamics of forest ecosystem development. Such data include temperature indicators, precipitation levels, air humidity, and other climatic parameters, which make it possible to trace the relationship between climatic conditions and forest health. However, traditional approaches have their own limitations, such as significant time and resource expenditures, limited territorial coverage, and insufficient accuracy and detail of the information obtained. In this regard, it is advisable to combine traditional methods with modern technologies, in particular by applying geographic information systems and remote sensing tools for more effective monitoring and management of forest resources.

Traditional forest monitoring methods demonstrate effectiveness in local studies; however, they also have certain disadvantages. Ground–based observations usually cover only individual sites, which makes it impossible to form a comprehensive picture of the state of the forest ecosystem. In addition, such approaches require considerable human and financial resources. At the same time, modern technologies such as geoinformation analysis, remote sensing, and machine learning algorithms are becoming increasingly popular among researchers and forestry specialists due to their efficiency and innovative approach.

Modern technological development makes it possible to significantly improve the effectiveness of forest ecosystem monitoring through the integration of various data sources. The combination of satellite observation, geographic information systems, and unmanned aerial vehicles provides оперативе and highly accurate information on forest conditions.

Table 2. Main methods for assessing the condition of forest ecosystems

No.	Method name	Method characteristics
1	**Forest area inventory**	This method is based on detailed inventory and forest management processes. Forest inventory involves the establishment of sample plots in designated forest stands and plantations, while forest management planning ensures land delineation, land classification, and the calculation of timber stock according to age categories.
2	**Forest mensuration**	This method is aimed at determining critical stand characteristics such as species composition, age, density, structure, and tree diameters. It enables forest management organizations to understand changes in forest structure under the influence of anthropogenic and natural factors, which is of key importance for maintaining biodiversity and ecological diversity.
3	**Assessment of indicators**	The evaluation of certain indicators of forest stand condition, such as density, tree height, timber volume, as well as the presence of pests and pathogens, helps determine the overall health status of forest areas.
4	**Sample–based regional survey**	This method consists in analyzing tree parameters and forest cover characteristics in selected areas, which contributes to the collection of detailed data on the structure and functioning of forest ecosystems. This creates an in–depth database for further analysis and forecasting of forest dynamics.
5	**Tree condition monitoring**	This method is focused on identifying signs of diseases and pests in trees and assessing their spread, thus allowing prompt control of negative changes and prevention of potential large–scale damage.
6	**Satellite imagery**	This is an effective method for obtaining spectral information on vegetation cover. It makes it possible to assess the condition of forest areas, sanitary condition, logging areas, and other important parameters, as well as to track the dynamics of changes in forest cover over large territories.

Under the conditions of modern information technology development, the use of automated data analysis systems for fire danger forecasting is becoming especially relevant. Such systems are based on mathematical models that take into account meteorological indicators, vegetation condition, historical fire data, and other parameters.

One of the promising areas is the application of machine learning methods, which make it possible to identify hidden patterns in large datasets. This allows the accuracy of fire occurrence forecasting to be improved and preventive measures to be taken in a timely manner.

An important component of modern monitoring is the integration of various sources of information into a single system. For example, the combination of satellite observation data, ground–based sensors, and weather stations makes it possible to obtain a more complete picture of the state of forest ecosystems.

Early warning systems are also being actively introduced, automatically signaling an increase in the level of fire danger. Such systems may be used for the оперативе notification of the relevant services and the population.

The use of modern digital technologies in forest monitoring significantly increases the efficiency of natural resource management and contributes to reducing the risk of large–scale fires.

A special role is played by the use of vegetation indices, in particular NDVI, which makes it possible to assess the condition of vegetation cover and identify areas of stress or damage. This allows potentially dangerous sites, where the risk of fire occurrence is elevated, to be identified in advance.

Thus, the introduction of digital technologies into the monitoring system is a key direction for increasing the efficiency of forest resource management.

One of the most advanced and at the same time effective methods of monitoring forest areas in the 21st century is satellite mapping combined with continuous remote monitoring. The use of satellite imagery makes it possible to obtain an objective and informative assessment of forest condition, track changes in ecosystems, and plan appropriate measures for their conservation. Satellite mapping technologies provide a large volume of relevant data that may be useful for various purposes. For example, by analyzing image tones, the typical green color of forest areas can be identified, since chlorophyll, which is the main pigment of plants, absorbs light predominantly in the green spectrum. This makes it possible to distinguish forested areas and create accurate maps of their location.

Satellite imagery also makes it possible to analyze forest stand density, providing an opportunity to assess forest condition in different regions. Areas with higher tree density are usually represented in darker shades in images, since tree crowns and branches block sunlight. This makes it possible to identify areas with high forest density, which indicates good forest condition and ecological stability within the relevant territories. This effect is clearly illustrated in Fig. 5 [15].

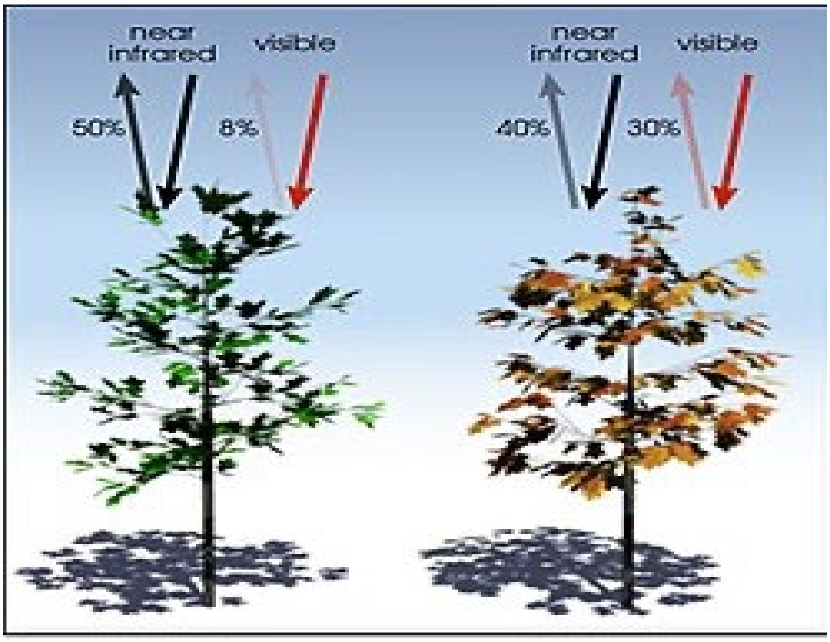


Figure 5. Application of NDVI for the identification of healthy and affected plants

Satellite imagery makes it possible to carry out a detailed analysis of the structure of forest areas. The use of modern data processing algorithms facilitates the identification of different tree species, the determination of crown parameters, and the detection of trees, roads, and other structural elements. This approach ensures the assessment of forest ecosystem biodiversity, the identification of areas in poor condition, and the development of priority measures for their restoration and conservation. See Fig. 6.

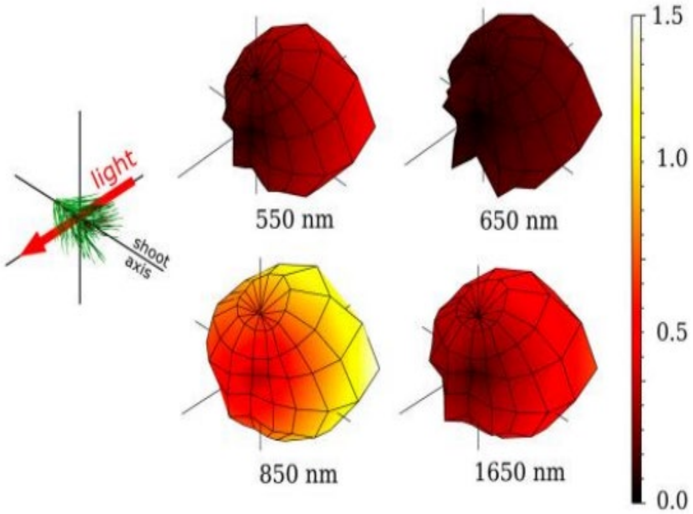


Figure 6. Scattering phase functions of a Scots pine shoot sample measured at four different wavelengths; the illumination geometry is shown in the upper left corner [16].

The analysis of changes in forest cover is one of the key areas of satellite imagery application. Comparing images taken at different time periods makes it possible to assess the dynamics of degradation processes caused by deforestation, the spread of diseases and pests, as well as spatial changes in the distribution of forest areas. Such information is of crucial importance for the development of strategies aimed at the conservation and restoration of forest resources.

In addition, satellite imagery plays an important role in the detection of forest fires and the assessment of their extent. The analysis of anomalies in the color and structural characteristics of images helps identify the presence of fire and trace its spread. These data contribute to a rapid response, including the organization of fire suppression measures and the minimization of damage caused by natural disasters. Figure 7 presents the spectral reflectance characteristics of certain woody components, such as tree trunks and individual pieces of bark [44].

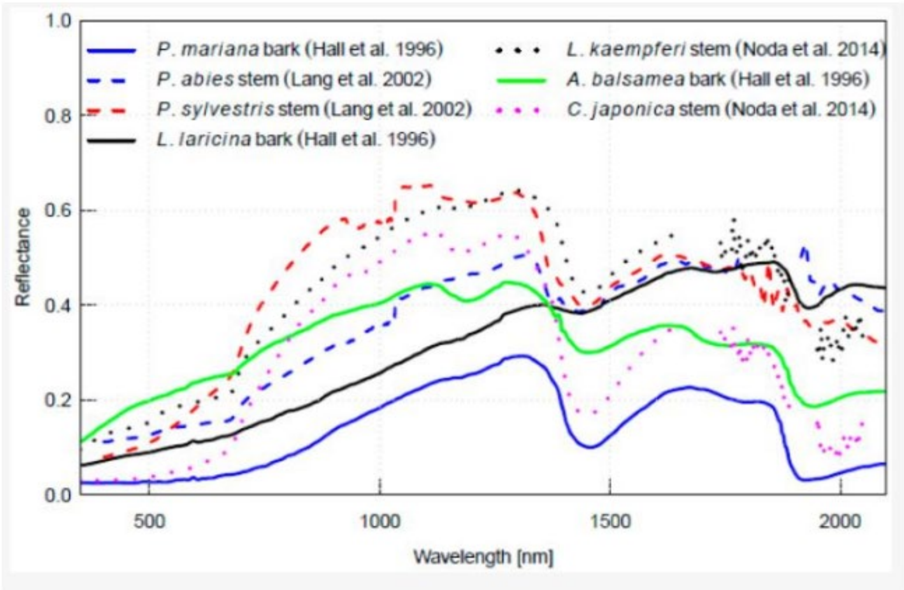


Figure 7. Reflectance spectra of woody components (tree trunks or pieces of bark) [41].

Firefighting technologies. The following methods are used to combat forest fires:

Various methods are used to combat forest fires depending on the type of fire, its scale, weather conditions, terrain, and available resources. In particular, the edge of a surface fire may be beaten with green branches or burlap in order to move burning particles toward the center of the fire and reduce combustion intensity. In addition, the fire edge may be covered with soil using shovels or special devices, which helps mechanically suppress the flames, cool combustible materials, and restrict air access. To limit the spread of fire, mineralized strips and trenches are created with the help of cutters, trench-digging machines, bulldozers, or hand tools, clearing the surface down to the mineral soil layer. One of the effective methods is also backburning, when the area in front of the advancing fire front is intentionally burned to create a protective strip free of combustible material. In certain cases, explosives may be used to create trenches and barriers or to suppress flames by means of ejected soil and shock waves. In order to prevent the uncontrolled spread of prescribed burning, it is carried out from existing control lines, such as forest roads, clearings, ditches, wide watercourses, or specially created mineralized strips. Fire suppression may also be performed with motor pumps, as well as by delivering water from airplanes and helicopters, which cools burning materials and contributes to the cessation of combustion. In addition, chemical agents are used to slow the spread of fire, reduce oxidation processes, cool combustible materials, and limit oxygen access. Under certain conditions, artificial precipitation may also be induced by acting on cloud fronts with special substances delivered by artillery or aircraft. [31].

The application of various firefighting methods requires clear planning and coordination of actions among units. In this context, it is important to determine the optimal fire suppression strategy, which depends on the scale of the fire, its type, and the available resources.

Particular importance is attached to the fire localization strategy, which involves limiting fire spread by creating barriers and carrying out controlled burning. This approach makes it possible to minimize the affected area and reduce risks to the environment.

Modern approaches to fire suppression also involve the use of specialized software tools for modeling fire development. This makes it possible to predict fire behavior and make more informed decisions regarding resource deployment.

An important factor is the safety of personnel involved in firefighting. This requires an adequate level of training, the use of personal protective equipment, and compliance with established safety protocols.

Thus, effective forest fire suppression requires a comprehensive approach that combines various methods and technologies.

The effectiveness of applying different forest fire suppression methods largely depends on the type of fire, weather conditions, terrain, and available resources. For example, mechanical methods (such as the creation of mineralized strips) are most effective for containing surface fires, whereas aerial firefighting is advisable in the case of large crown fires.

Chemical agents help slow the spread of fire; however, their use requires consideration of environmental consequences. In turn, the combined application of different methods (mechanical, water–based, and chemical) ensures the best results in firefighting.

An important component is also the speed of response, since extinguishing a fire at its early stages significantly reduces resource expenditures and the scale of damage.

In addition to traditional forest fire suppression methods, innovative technologies and approaches are becoming increasingly important under modern conditions. In particular, unmanned aerial vehicles equipped with thermal imaging cameras are being actively introduced, making it possible to rapidly detect fire outbreaks even in hard–to–reach areas and under conditions of limited visibility.

An important direction of development is the use of geographic information systems (GIS), which ensure the integration of various types of data–meteorological, topographic, and satellite data–for the creation of detailed fire danger maps. This makes it possible not only to respond promptly to fires but also to plan preventive measures.

Modern methods also include the use of automated fire detection systems based on smoke, temperature, and infrared radiation sensors. Such systems provide continuous monitoring of territories and significantly reduce response time to ignition.

Of particular importance is the application of mathematical models for predicting fire spread. These models take into account wind speed, vegetation type, terrain, and other factors, making it possible to determine the probable direction of fire movement and optimally allocate forces and resources for its suppression.

An important aspect is the environmental safety of the methods applied. Certain firefighting agents, particularly chemical substances, may have a negative impact on the environment; therefore, their use must be justified and controlled. In this regard, environmentally safe technologies, such as the use of water vapor, bio–based foams, and the minimization of interference with natural processes, are gaining increasing popularity.

The issue of logistics and firefighting support is no less important. The effectiveness of fire suppression largely depends on the speed of equipment delivery, the availability of water resources, the condition of roads, and the organization of interaction between units. Under difficult conditions, mobile command posts are used to ensure real–time coordination of actions.

Special attention should be paid to personnel training, since the success of fire suppression depends not only on technical support but also on the professional skills of rescuers. Regular drills, training, and emergency response exercises are a necessary condition for improving the effectiveness of fire units.

Thus, the modern forest fire suppression system should be based on a combination of traditional methods and the latest technologies, ensuring a comprehensive approach to solving this problem. The integration of innovative solutions, improvement of organizational capacity, and efficient use of resources make it possible to significantly reduce the scale of fires and minimize their negative consequences for the environment and society.

Particular attention should also be paid to the issues of strategic fire risk management, which involves the systematic analysis of potential threats and the development of long–term fire prevention measures. Such an approach is based on assessing the probability of fire occurrence, identifying the most vulnerable forest areas, and developing appropriate response scenarios. This makes it possible not only to reduce the number of fires but also to minimize their consequences if they occur.

An important element of the modern fire protection system is the implementation of the principles of risk–oriented management. These principles provide for the priority allocation of resources to the most dangerous areas characterized by high fire load, a significant amount of dry vegetation, or difficult access conditions. Such an approach increases the efficiency of resource use and ensures a more rational organization of fire protection measures.

In addition, the integration of fire protection systems with other areas of forestry plays a significant role. In particular, sanitary cuttings, tending of forest plantations, clearing of logging residues, and the creation of firebreaks contribute to reducing the amount of combustible material and lowering the risk of fire occurrence. Thus, preventive measures are an integral component of an effective protection system.

Consideration of the social factor is equally important. A high level of fire danger is largely associated with human activity; therefore, information and awareness–raising work among the population is one of the key directions of prevention. The organization of educational campaigns, installation of warning signs, restriction of access to forests during fire–hazard periods, and strengthening control over compliance with fire safety regulations make it possible to significantly reduce the number of ignition cases.

Under modern conditions, the development of automated decision support systems is also an important direction. Such systems use large volumes of data and make it possible to quickly assess the situation, predict fire development, and determine the optimal ways of suppressing it. The use of artificial intelligence and data analysis algorithms opens up new opportunities for improving the effectiveness of fire safety management.

The issue of adapting the fire protection system to climate change is of particular importance. Rising air temperatures, reduced precipitation, and longer dry periods require a revision of existing approaches to the organization of fire safety. This involves improving forecasting systems, increasing the readiness of fire units, and introducing new firefighting technologies.

Thus, effective forest fire suppression should be based on a combination of preventive, organizational, technical, and innovative measures. Only a comprehensive approach that takes into account natural, technogenic, and social factors can ensure an adequate level of protection of forest ecosystems and minimize the negative consequences of fires.

Research Conditions. The State Enterprise “Krasnopilskyi Agrolisgosp” is located in the south–eastern part of Sumy Oblast and covers an area of 11,522 hectares. The forests in this area develop under conditions of a temperate continental climate with a sufficient amount of precipitation. However, certain natural factors, including high air temperature, low soil moisture, and the presence of young coniferous plantations, may contribute to the risk of fire occurrence and spread. Water bodies and rivers in the region can significantly assist in fire suppression; however, their effectiveness decreases when precipitation is insufficient.

The total area of the forest fund assigned to the enterprise is 11,522 hectares, of which 9,548.1 hectares are covered with forest vegetation. These territories are used for various purposes, including environmental protection, historical and cultural purposes, scientific research, recreation and health improvement, and protective functions.

According to forest site zoning, the territory of the agrolisgosp belongs to the North–Eastern Sumy Forest–Steppe. Oak forests, maple–linden–oak forests, and floodplain meadows typical of the Central Russian Forest–Steppe District predominate here. This zoning was developed by the specialist S. A. Hensiruk.

The climate in the area of the enterprise is temperate continental. It is characterized by a long warm summer with a moderate amount of precipitation and a relatively mild winter.

The natural conditions of this region may contribute to the occurrence of forest fires. For example, high temperatures combined with low soil moisture increase the risk of ignition and complicate fire suppression. The presence of a significant proportion of deciduous tree species increases the amount of combustible material, facilitating the spread of flames. At the same time, rivers and ponds provide the necessary access to water for fire suppression; however, in periods of precipitation deficit, the water level in these bodies may decrease, which makes firefighting more difficult.

The organization of forest fire protection involves the implementation of a systematic set of measures aimed at preventing the occurrence and spread of fires, as well as ensuring the prompt and effective elimination of ignition sources. This process includes several key stages:

Introduction of modern technologies. The use of innovative methods for fire detection and monitoring, in particular drones with thermal imaging cameras and satellite observation systems. However, under the current conditions of martial law, such methods are limited, since the use of drones is prohibited in border regions.

Monitoring of the forest environment. Continuous observation of forest areas to ensure the timely detection of threatening factors and the application of preventive measures.

Development of fire protection plans. The creation of detailed response strategies in the event of fire occurrence, including cooperation with other emergency rescue services and ensuring the availability of the necessary resources and equipment.

Organization of training activities. Regular improvement of personnel qualifications in the field of fire safety, the conduct of training sessions, and the provision of proper theoretical and practical training in specialized institutions.

Interaction with local communities. Active involvement of the local population in the fire prevention process through awareness campaigns, training activities, and close cooperation with the media to disseminate information on fire danger.

Formation of a specialized fire protection service. Establishment of an organization responsible for the detection, localization, and suppression of fires, equipped with appropriate resources and qualified personnel.

Establishment of fire safety standards. The development and implementation of clear regulations prohibiting activities that may potentially cause ignition, such as open burning, smoking, or the use of firearms near forests.

The effective organization of the forest fire protection system also requires a clear distribution of functions and responsibilities among different stakeholders. These include state authorities, forestry enterprises, rescue services, and local communities.

The coordination of their activities is carried out through the creation of unified management centers that ensure prompt decision–making and control over the implementation of measures.

The issue of financing is equally important, since ensuring an effective fire protection system requires substantial material resources. Investment in modern technologies, equipment, and personnel training is a necessary condition for improving the effectiveness of this system.

International cooperation also plays an important role, as it makes it possible to adopt advanced experience and implement best practices in the field of forest fire management.

In conclusion, only a comprehensive approach to the organization of fire protection can ensure an adequate level of safety for forest ecosystems.

The organization of forest fire protection should be based on the principles of systematicity, continuity, and adaptability. This means that all measures should be interconnected and aimed not only at fire suppression, but also at fire prevention.

An important element is the creation of an integrated management system that includes monitoring, forecasting, planning, and operational response. Such a system makes it possible to ensure effective coordination among different services and the optimal use of resources.

In addition, it is necessary to take into account international experience in the field of forest fire management, which involves the active use of digital platforms, automated alert systems, and analytical forecasting models.

All the above–mentioned measures are basic elements of the forest fire protection system aimed at preserving natural ecosystems.

Assessing the effectiveness of the monitoring and observation system for forest fires is a key stage in determining the success of measures aimed at protecting forests from fire. This process includes the analysis of various types of data, such as the results of monitoring potential fire risks, the prompt detection of ignitions at early stages, the timeliness of response to incidents, and the effectiveness of fire suppression measures.

During the assessment, actual results are considered in comparison with the planned goals and indicators. Important aspects include the accuracy and speed of fire detection, the effective use of available resources and equipment, the scale of fire spread, as well as the assessment of damage caused to the natural environment and people. Such actions make it possible to identify the strengths and weaknesses of the existing system, highlight problematic areas, and propose measures to improve fire management strategies. The obtained results serve as a basis for making rational decisions and developing updated fire protection strategies.

The key factors affecting the effectiveness of forest protection measures are presented below:

The effectiveness of forest protection measures depends on several key factors. One of the most important among them is the speed of fire detection, since the timely identification of an ignition source makes it possible to respond rapidly and prevent the fire from spreading over large areas. Equally important is the accuracy of determining the fire location, because effective resource management and proper organization of response actions depend on correct localization. A significant role is also played by alert and communication systems, as well-established coordination between stakeholders and the rapid transmission of information minimize response time and support efficient decision-making. In addition, the promptness of fire response and suppression is essential, as the ability to mobilize the necessary personnel, machinery, and equipment in time significantly reduces the scale of damage and contributes to successful fire localization at the early stages.

The implementation of regular assessment and improvement of monitoring and response systems is an integral component of the long–term strategy for combating forest fires [36].

Research Results. The use of measures aimed at protecting forest plantations from forest fires is an important component of forestry activities [38]. Several methods and measures applied at the specified enterprise to protect forests from fires are presented below:

Monitoring and surveillance: this measure includes fire warning systems that may be installed in forests, continuous patrolling and observation for the presence of fires, awareness–raising activities among the population, and the installation of special mechanical barriers along the potential path of fire spread. Owing to this measure, incidents can be detected at the initial stages of their development (Table 3).

Table 3. Preventive and precautionary forest fire protection measures Implemented at the enterprise

Measure	Result
Barriers manufactured and installed	3
Warning signs installed	4
Maintenance of mineralized strips and firebreaks	Not carried out due to the evacuation of the population from the Krasnopillia and Myropillia territorial communities and the destruction of infrastructure in the villages and settlements of the district
Preventive talks at schools on compliance with forest fire safety rules	Not carried out
Presentations in the mass media	Not carried out

The organization of patrolling and fire suppression is an important component of the strategy for protecting forest areas. Regular inspection of forests contributes to the detection of potential fires at an early stage and enables an immediate response. Foresters use fire extinguishers, fire tankers, and other specialized equipment, which is listed in detail in Table 3.

Table 4. Forest firefighting equipment available at the enterprise

Total firefighting equipment, units	ZIL	Others	Availability of motor pumps	Availability of RLO
0	0	0	1	10

Firebreak corridors are clearings created by removing vegetation along the boundaries of forest areas or between individual forest sections. They are intended to reduce the intensity and rate of forest fire spread by serving as buffer zones.

Informing the public and forest users is one of the key aspects of ensuring fire safety. Priorities include educational activities regarding fire safety rules, explanation of bans on the use of open fire in hazardous areas, as well as reminders about the need to promptly notify the relevant services in the event of fire occurrence. The timely dissemination of such knowledge can significantly reduce the number of fire incidents.

Technical means and equipment also play a special role in fire protection. They are used for the prompt detection of ignition sources, the direct suppression of fires, and their further localization. Such means include fire engines, aviation resources, in particular helicopters, water supply systems, hand tools for firefighting, and other specialized equipment. An important aspect of the effective functioning of this equipment is regular technical maintenance, as well as systematic personnel training through drills. Thus, all available resources at the disposal of the relevant services require a comprehensive and coordinated approach in order to ensure maximum effectiveness in combating forest fires. The available resources of the agrolisgosp are listed in Table 5.

Table 5. Availability of fire suppression resources and firefighting equipment [14]

No.	Name of firefighting equipment and fire suppression resources	Availability as of 01.01.2025
1	Fire engines AC–40 and ARS–14	0
2	Forest fire modules	1
3	Patrol vehicle	2
4	Motor pumps	1
5	Fire beaters	7
6	Fire hoses	80
7	Fire nozzles	2
8	Wheeled tractors	2
9	Forest ploughs, soil throwers	1
10	Backpack forest fire extinguishers	10
11	Chainsaws	1
12	Shovels	25
13	Axes	5
14	Rakes	10
15	Wetting agents	0
16	Canisters	10
17	Radios, total	1
18	Duty clothing and special footwear	10
19	First aid kits	1
20	Cups for drinking water	15
21	Containers for drinking water	3

The implementation of the fire protection action plan at the enterprise involves the following stages:

The implementation of the fire protection action plan at the enterprise involves several interrelated stages. First of all, it is necessary to develop a list of measures aimed at ensuring fire safety, taking into account existing risks and current legislative requirements. After that, responsible persons or teams should be appointed to organize the implementation of the plan and supervise its execution. An equally important stage is the provision of the necessary resources, including materials, equipment, and funding, required for carrying out the planned activities. The next stage involves the practical implementation of preventive and operational measures intended to prevent fires and ensure safety. At the same time, continuous monitoring of the implementation process should be carried out in order to promptly identify shortcomings and improve the effectiveness of the fire protection system. In addition, fire safety plans and procedures must be regularly updated with regard to technological development, new regulatory requirements, and conclusions drawn from previous experience.

The analysis of forest protection measures at the enterprise demonstrated the effectiveness of certain methods. The monitoring system confirmed its efficiency by enabling the detection of fires at their initial stages. Patrolling and prompt fire suppression are key components of fire management. Educational and informational campaigns among the public contributed to raising awareness and fostering a responsible attitude toward forest resources. For the effective protection of forest plantations, it is necessary to apply various methods and means, taking into account the specific features of local conditions and landscape characteristics.

The conducted analysis indicates the positive impact of the implemented measures on reducing the level of fire danger. In particular, there is a tendency toward a decrease in the number of ignition cases and the area of damaged territories.

At the same time, the obtained results indicate the need for further improvement of the fire risk management system, in particular through the expansion of the material and technical base, an increase in the level of automation of monitoring processes, and improved coordination between services.

Thus, the effectiveness of fire protection measures directly depends on the comprehensiveness of the approach and the level of implementation of modern technologies.

The assessment of the effectiveness of the forest fire monitoring and control system is one of the key stages in determining the success of measures aimed at protecting forests from fire. This process includes the analysis of a large volume of data, including the results of monitoring fire danger levels, the timeliness of fire detection, the promptness of response to fire incidents, and the effectiveness of fire suppression [1].

As part of the assessment, actual achievements are compared with planned goals and performance indicators. This includes the analysis of such parameters as the accuracy and speed of fire detection, the optimal use of resources and equipment, as well as the assessment of the scale of fire spread, its destructive impact on the environment, and the risks to human life [49].

The results of such an assessment help identify the strengths and weaknesses of the monitoring system, determine critical problem areas, and make it possible to formulate proposals for improving forest protection measures and strategies. On the basis of these data, appropriate measures are developed to enhance the effectiveness of fire protection.

The main factors influencing the effectiveness of fire protection measures are described below:

Fire detection. An important characteristic is the speed of ignition detection. The use of modern technologies–satellite systems, drones, and automatic fire indicators–makes it possible to significantly improve this parameter [4].

Geolocation accuracy. Providing precise coordinates of the fire location is crucial for effective resource management and response. Such tools as modern geographic positioning systems ensure a high level of accuracy [20].

Alert and communication systems. The level of effectiveness of interaction between the services involved in fire suppression is analyzed. Automated alert systems and clear coordination of unit activities have a positive impact on response effectiveness [31].

Promptness of response and fire suppression. The capabilities of resource provision (firefighting equipment and machinery) and staff qualifications are evaluated. Clearly organized and rapid response facilitates fire localization at the initial stages, minimizing its impact [22].

Special attention is also paid to the assessment of fire protection lines, that is, their contribution to restraining the spread of fire. The key aspects of such an assessment include:

Width and length. The lines must be wide enough to stop the fire while at the same time covering the entire area of potential risk.

Condition and maintenance. Regular clearing of vegetation and ensuring accessibility for rescuers and equipment significantly increase the effectiveness of the lines [21].

Location. The placement of fire lines should cover the most hazardous areas and take into account natural barriers.

Analysis and adaptation. Continuous monitoring and updating in accordance with environmental or climatic changes increase their effectiveness [29, 37].

The analysis of data from the Forest Fire Record Book, in which all fire incidents within the enterprise territory are registered, made it possible to establish that the number of fires per year after the implementation of preventive measures in 2023 decreased compared with the period prior to the introduction of these measures. At the same time, this decrease may be partially explained by the reduced number of forest visitors during 2023, which accordingly lowered the probability of fire occurrence. This aspect may be characterized as a human factor, which is difficult to influence significantly due to the limited number of available tools, in particular preventive talks and lectures, which often demonstrate insufficient effectiveness. Despite this, the problem of fire occurrence remains relevant. However, it should be noted that in the period from 2022 to 2023, not a single fire was recorded within the enterprise territory, whereas in 2021 and previous years, two to three fire incidents were usually registered annually (see Table 6).

It is advisable to evaluate the effectiveness of fire protection efforts on the basis of the efficiency of preventive measures. In this context, attention should also be paid to the positive trend in the reduction of the area affected by fires. In particular, the average area of forest land damaged by fire in 2021 amounted to 0.5 km^2, whereas in previous years it reached 2.8 km^2 (see Table 6). Thus, the results of the implemented measures demonstrate a favorable trend. This provides grounds for asserting that the preventive actions introduced within the enterprise territory are effective in preventing the occurrence and spread of forest fires.

Table 6. Forest fires on the territory of the enterprise

Date	Area at the time of fire occurrence	Forest area affected by the fire
06.06.2015	0.4	0.7
30.06.2015	1.2	3.2
25.07.2015	0.6	0.6
27.08.2016	0.3	0.5
08.09.2016	0.3	0.3
18.07.2017	0.8	1.0
20.08.2017	0.7	1.2
22.08.2019	0.4	4.2
17.09.2021	0.5	0.7
31.07.2022	1.0	1.5
28.08.2023	1.3	2.0
02.08.2024	2.0	2.1

The analysis of the data presented in Table 6 and visualized in Figure 8 in the form of a graph allows for a well-grounded conclusion that the positive results achieved are not accidental. They are the result of a systematic approach to organizing fire safety and the effective implementation of a комплекс of preventive measures at the enterprise. In particular, the graph clearly shows a steady downward trend in the number of fire incidents over the studied period, which indicates an increased level of control and timely response to potential threats.

Particular attention should be paid to the effectiveness of fire response teams. Due to their оперативність and coordinated actions, in most cases fires are successfully localized at early stages. This is confirmed by the data for 2021, where the fire area at the time of detection is almost equal to the final burned area. Such a result indicates a high level of preparedness of the services and the effectiveness of early fire detection systems.

The evaluation of the implemented measures also confirms their significant contribution to reducing the risk of fire occurrence. In particular, firebreaks (mineralized strips) and specially equipped fire lines play an important role. They not only limit the spread of fire but also create conditions for rapid access of firefighting equipment to ignition sites. The availability of appropriate infrastructure – including roads, water sources, and observation points – significantly increases the efficiency of fire suppression.

In addition, territory monitoring is an important component of the system. The use of modern surveillance tools, including video monitoring, satellite observation, and unmanned aerial vehicles (drones), makes it possible to quickly detect fire outbreaks even in hard-to-reach areas. Patrolling and regular inspections have also proven their effectiveness, as they contribute not only to fire detection but also to prevention by ensuring compliance with fire safety regulations.

At the same time, despite the achieved results, there is still potential for further improvement of the system. In particular, it is advisable to strengthen coordination between different fire service units, implement unified digital platforms for real-time information exchange, and expand the use of innovative technologies such as automated risk analysis and fire prediction systems.

Additionally, attention should be given to improving staff qualifications, conducting regular training and drills, and enhancing the regulatory framework. The comprehensive implementation of these measures will not only maintain the achieved level of safety but also ensure further reduction of fire risks.

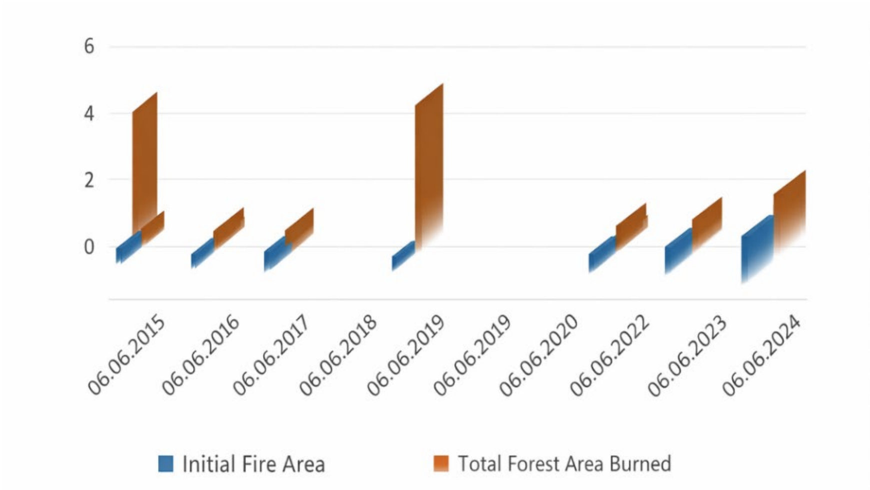


Figure 8. Dynamics of fire occurrence within the agrolisgosp territory

Thus, the results of the study clearly demonstrate that a systematic approach to fire protection – including infrastructure solutions, monitoring, patrolling, and rapid response – is an effective tool in combating fires and ensuring the safety of the enterprise.

After the end of military operations in the forest areas under the ownership of the agrolisgosp, it would be advisable to improve the system of interaction between fire services and introduce innovative technologies for monitoring potential threats. The application of such solutions would significantly increase the level of safety and provide even better fire protection for the enterprise.

Knowledge of the specific features of forest fire spread, as well as the rate of its propagation along the front, flanks, and rear, is essential for analyzing its further behavior. This makes it possible to accurately assess the area of ignition within a certain territory over a specific period of time and to optimally plan measures for fire localization and suppression. Such an approach contributes to the effective calculation of the resources and technical means required for emergency response, as well as for the protection of residential areas and other strategically important facilities located within the risk zone.

The introduction of adjusted coefficients and the refinement of the geometric shape of forest fire spread would improve the quality of managerial decision–making regarding the localization and elimination of ignitions. This would also have a positive effect on the efficiency of allocating human resources and equipment involved both in firefighting and in preventing threats to settlements, material assets, and infrastructure.

One of the main reasons for the insufficient effectiveness of measures aimed at the prevention and suppression of forest fires in the modern context is a whole range of factors:

One of the main reasons for the insufficient effectiveness of measures aimed at preventing and suppressing forest fires under modern conditions is a combination of interrelated problems. These include the unsatisfactory level of preventive work with the population regarding fire safety both in forest areas and in settlements, the insufficient provision of local self-government bodies with the resources necessary for fire prevention and suppression, the lack of a trained network of volunteer fire brigades or instructors in many forest regions, the absence of an effective system for informing citizens about emergencies and alerting them during such events, the shortage of firefighting resources including specialized equipment and water supply sources, as well as the accumulation of flammable waste and weeds around settlements.

To eliminate these problems and reduce the catastrophic consequences of natural forest fires, it is necessary to improve a set of preventive and operational measures, which may be divided into two groups:

Organizational and legal measures should include the improvement of the legislative framework regulating the protection of forest ecosystems and the sustainable development of forestry, the development of modern methods for monitoring and forecasting forest fire spread, including improved algorithms for calculating fire danger indicators, and the intensification of information and awareness-raising work among the population through media platforms. They should also involve strengthening control over compliance with fire safety regulations in areas adjacent to forest stands, economic facilities, and recreation sites, creating specially equipped recreational zones arranged in accordance with fire safety requirements, expanding opportunities for the rapid collection, analysis, and transmission of information on forest fires to the relevant services, and improving methods for carrying out urgent emergency rescue operations during the elimination of large-scale fires.

Engineering and technical measures should include the creation of firebreaks, mineralized strips, and protective forest edges intended to limit the spread of forest fires, as well as the preparation of the resources and means necessary for preventing their occurrence and ensuring effective suppression. Such measures should also provide control over the level of preparedness of forces and equipment for counteracting fire danger, including the deployment of operational groups to regions with an increased risk of forest fires. In addition, they should involve regulating the condition of forest ecosystems through the optimization of stand composition, the clearing of logging sites, the removal of clutter from non-logging areas, and the carrying out of sanitary cuttings and similar operations. Considerable importance should also be attached to improving methods, technologies, and means of forest fire detection, including continuous duty at fire observation posts and towers, the integration of satellite and aerial monitoring systems, and ground patrolling. Another important task is the creation and training of non-staff fire-rescue units in settlements and at economically important facilities located in or near forest areas.

This set of measures is aimed at increasing the effectiveness of the system for preventing large–scale forest fires, reducing their negative consequences, and ensuring coordinated interaction among the management structures of the Unified State System for Emergency Prevention and Response, local self–government bodies, executive authorities at various levels, and specialized units for suppressing natural fires.

Conclusions

As a result of the conducted research, the problem of the occurrence and spread of forest fires within the State Enterprise "Krasnopilskyi Agrolisgosp" was comprehensively analyzed, and a set of organizational, technical, and preventive measures aimed at improving the efficiency of fire protection of forest ecosystems was substantiated.

It was established that forest fires are a complex multifactorial phenomenon, the occurrence of which is caused by the interaction of natural and anthropogenic factors. At the same time, the human factor plays a decisive role and in most cases is the main cause of ignitions. Climatic conditions, in particular elevated temperatures, prolonged dry periods, and low humidity, also create a favorable environment for the rapid development of fires.

During the study, the characteristics of forest plantations within the enterprise territory that affect the level of fire danger were analyzed. In particular, the presence of coniferous species, a significant amount of forest litter, and dry vegetation increase the probability of fire occurrence and spread. At the same time, natural water bodies may act as a restraining factor, although their effectiveness depends on hydrological conditions.

The assessment of the existing monitoring and observation system showed that it is generally effective, especially in terms of early fire detection. At the same time, it was found that traditional monitoring methods have certain limitations related to insufficient territorial coverage and significant resource expenditures. In this regard, the expediency of introducing modern technologies, in particular remote sensing of the Earth, geographic information systems, and automated data analysis systems, was substantiated.

The conducted analysis of measures aimed at protecting forest plantations from fires confirmed the effectiveness of applying a set of preventive and operational actions, such as patrolling, the creation of mineralized strips, the use of specialized equipment, and informational and awareness–raising work among the population. It was established that timely detection and prompt response are the key factors in the successful localization of fires and the minimization of their consequences.

The analysis of statistical data indicates a positive trend toward a reduction in the number of fires after the implementation of appropriate measures, which confirms their practical effectiveness. At the same time, a number of problems were identified, in particular insufficient material and technical support, limited financial resources, as well as imperfections in the system of informing and interaction between services.

Based on the conducted research, improvements to the fire protection system were proposed, including the introduction of innovative monitoring technologies, an increase in the level of process automation, the development of an early warning system, as well as strengthened coordination among all stakeholders.

Particular attention should be paid to increasing the level of environmental awareness of the population, which would make it possible to reduce the number of fires caused by the human factor. The development of the system of staff training and professional preparation is also important, as it will ensure a more effective response to emergency situations.

Promising directions for further research include the development and implementation of intelligent fire safety management systems based on artificial intelligence technologies, big data analysis, and mathematical modeling. This would make it possible to increase the accuracy of fire danger forecasting and improve the effectiveness of managerial decision–making.

Thus, the results of the study confirm the need for a comprehensive approach to the organization of forest fire protection, combining traditional methods and modern technologies, ensuring the efficient use of resources, and contributing to the preservation of forest ecosystems.

REFERENCES

1. Arefieva S.I., Barladin O.V., Skliar O.Yu., (2011) Development of a GIS server for the forestry sector of Ukraine. Scientific Notes of Tavrida National University named after V.I. Vernadsky. Series: Geography, Vol.24, N.3, P.24–32.
2. Balanovskyi O.P., Lapinskyi V.P., Prykhodko O.M., (2018) The role of forestry in the economy of Ukraine. Economics and Forecasting, N.2, P.55–61.
3. Barladin O.V., Mykolenko L.I., (2011) Use of Earth remote sensing data for the creation of electronic resources. Modern Achievements of Geodetic Science and Production, N.1, P.162–167.
4. Binkley C.S., DeLuca T.H., Hawkins B.J., (2017) Opportunities and challenges of managing forests for multiple ecosystem services. Frontiers in Ecology and the Environment, Vol.15, N.2, P.64–71. DOI: 10.1002/fee.1454.
5. Bohovyn A.V., (2011) Types of biodiversity categories under conditions of anthropogenic transformation of ecological systems. Ecology and Noospherology, Vol.22, N.3–4, P.73–83.
6. Boiko V.V., Hoidych A.V., Kovalchuk L.S., (2019) Modeling of optimal options for restoring forest funds of settlements. Ecology and Nature Management, N.4, P.67–72.
7. Bondar A.O., Vakuliuk V.D., Orlov O.M., (n.d.) Restoration of Podilian hail forests damaged by ice. Forestry and Agroforestry Reclamation, N.103, P.128–129.
8. Borysenko A.V., Semenova O.V., Halimova O.I., (2021) Innovative approaches in forestry: global experience and prospects for application in Ukraine. Economic Bulletin of NTUU "KPI", Vol.2, N.37, P.21–29.
9. Concept of the State Target Program for the Development of Forestry of Ukraine for 2016–2020, (2025) Draft for discussion [Electronic resource]. Available at: http://dklg.kmu.gov.ua/forest/control/uk/publish/article?art_id=113516&cat_id=82872 (accessed: 28.05.2025).
10. Ferretti M., Fischer R., Mues V., Granke O., Lorenz M., Seidling W., (2017) Part II: Basic design principles for the ICP Forests Monitoring Networks. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.), Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde, Germany, 21 p.
11. Fisher R.F., Binkley D., (2018) Ecology and Management of Forest Soils. 5th ed. Wiley-Blackwell. ISBN: 978-1119504215.
12. Haida Yu., Popadynets I., Yatsyk R., et al., (n.d.) Forest genetic resources and their conservation. Ternopil: Textbooks and Manuals, P.208–288.
13. Havrylova I.M., Shapiro A.I., Lytvynenko V.P., (2021) Innovative technologies in forestry: experience of application in Ukraine. Economic Bulletin of Donbas, N.3(61), P.87–94.
14. Havryshok B.B., Potokii M.V., (2014) Cartographic method in retrospective-geographical studies of nature management (on the example of the Podilski Tovtry within Ternopil region). Scientific Notes of Ternopil Volodymyr Hnatiuk National Pedagogical University. Series: Geography, N.1, P.20–29.
15. Herasymov S.V., Zhovtonozhenko I.V., Miroshnichenko O.M., (2020) Efficiency of forest resource use in Ukraine: current state and prospects. Economics and Entrepreneurship, N.4(21), P.92–99.
16. Hujala T., Pykäläinen J., Karppinen H., (2015) Forest owner cooperation practices in Europe: An analysis of case studies. Small-scale Forestry, Vol.14, N.3, P.317–336. DOI: 10.1007/s11842-015-9296-9.
17. Klymenko S.M., Borysenko V.I., Pysarenko A.V., (2020) The state of forestry in Ukraine and ways of its optimization. Forestry and Agroforestry Reclamation, N.145, P.12–19.
18. Kondratiuk T.I., Tykhonov I.V., Mazur L.V., (2021) Legal regulation of forestry in Ukraine: current state and development prospects. Law and Safety, N.4, P.66–73.
19. Koricheva J., Gurevitch J., Mengersen K., (2019) Handbook of Meta-analysis in Ecology and Evolution. Princeton University Press. ISBN: 978-0691137292.
20. Koshel M.V., Yakubiv V.I., (2017) Influence of forestry activity on the structure of forest-steppe ecosystems. Scientific Bulletin of NLTU of Ukraine. Thematic Issue "Forestry and Agroforestry Reclamation", Vol.27.11, P.124–131.
21. Kovalov Yu.M., Petrov O.V., Lysenko V.I., (2020) Optimization of forest resource use on the example of Volyn region. Bulletin of Agrarian Science, N.5, P.43–49.
22. Lillesø J.P.B., Vaast P., Leisz S.J., (2020) Biodiversity, Forests and Community Development: Insights from Southeast Asia. Routledge. ISBN: 978-0367433385.
23. Martynenko S.I., Kravchenko Yu.A., Serhiienko I.M., (2017) State and prospects of forestry in Ukraine. Economics and Management, N.3(64), P.78–84.
24. Matviichuk V.P., Sydoruk T.V., Myronchuk O.M., (2021) Innovative aspects in forestry and their influence on the sustainable use of forest resources. Scientific Bulletin of NLTU of Ukraine. Thematic Issue "Scientific and Technical Progress and Effective Management of Agro-Industrial Production", Vol.31.11, P.111–117.

25. Melnychuk M.D., Harbar M.V., (2016) Formation of an aggregate indicator of forestry efficiency in the context of sustainable development. Scientific Bulletin of NLTU of Ukraine. Thematic Issue "Sustainable Development of Agro-Industrial Production", Vol.26.11, P.207–213.
26. Michel A., Seidling W., (2017) Forest Condition in Europe: 2017 Technical Report of ICP Forests. Report under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). BFW-Dokumentation 24/2017. Vienna: BFW Austrian Research Centre for Forests, 128 p.
27. Mieshkova V.L., (2013) Forest entomology and forestry. Plant Protection and Quarantine (interdepartmental thematic scientific collection), Vol.54, P.292–299.
28. Mykhailenko O.S., Smirnova L.M., Prykhodko O.M., (2021) Potential of forestry in Ukraine in the context of sustainable development. Scientific Bulletin of LNUVMBT named after S.Z. Gzhytskyi, Vol.27, N.109, P.128–135.
29. Nesterenko V.M., Lytvynenko V.P., Bondarenko V.S., (2021) Legal support for the rational use of forest resources. Forestry and Agroforestry Reclamation, N.152, P.34–41.
30. Nordén B., Appelqvist T., Bader P., et al., (2016) Adaptive management of forest biodiversity in Nordic countries: A systematic review. Forest Ecology and Management, Vol.360, P.375–385. DOI: 10.1016/j.foreco.2015.10.029.
31. Pan Y., Birdsey R.A., Phillips O.L., et al., (2011) A Large and Persistent Carbon Sink in the World's Forests. Science, Vol.333, N.6045, P.988–993. DOI: 10.1126/science.1201609.
32. Panchenko O.O., Pidhainyi O.I., Kozlovska L.M., (2021) Financial and economic mechanism of forestry management. Economics: Time Realities, N.2(39), P.104–111.
33. Particularly valuable forests for conservation: definition and management, (2015) Practical guide for Ukraine. 2nd ed. [Electronic resource]. 146 p. Available at: http://www.twirpx.com/file/864185/ (accessed: 28.05.2025).
34. Poliakova O.O., Hlushko L.V., Kryklia V.M., (2019) Features of forestry functioning under anthropogenic impact. Bulletin of Agrarian Science of the Black Sea Region, Vol.2, N.2(9), P.62–67.
35. Polishchuk B.V., (2018) Modern achievements and problems in studies of forest development and condition. Geodesy, Cartography and Aerial Photography, N.70, P.138–145.
36. Puettmann K.J., Coates K.D., Messier C., et al., (2020) A Critique of Silviculture: Managing for Complexity. Island Press. ISBN: 978-1642830571.
37. Rist L., Felton A., Samuelsson L., et al., (2021) Implementing landscape approaches to improve forest governance and catalyze transformative change. Forest Policy and Economics, Vol.125, Article 102473. DOI: 10.1016/j.forpol.2021.102473.
38. Savchuk S.O., Liubymova T.I., Kravchuk I.O., (2018) Features of the use of the forest fund for solving environmental problems of the regions of Ukraine. Forestry and Agroforestry Reclamation, N.138, P.23–30.
39. Schelhaas M.J., Nabuurs G.J., Schuck A., (2003) Natural disturbances in the European forests in the 19th and 20th centuries. Global Change Biology, Vol.9, N.11, P.1620–1633. DOI: 10.1046/j.1365-2486.2003.00684.x.
40. Seheda Yu.Yu., (2017) Reproduction of common oak (Quercus robur L.) plantations in the Right-Bank Forest-Steppe of Ukraine using planting material with a closed root system. Extended abstract of Candidate of Agricultural Sciences dissertation: 06.03.01 "Forest crops and phytomelioration". National University of Life and Environmental Sciences of Ukraine, Kyiv, 23 p.
41. Seidling W., Hansen K., Strich S., Lorenz M., (2017) Part I: Objectives, Strategy and Implementation of ICP Forests. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.), Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde, Germany, 12 p.
42. Semenchenko Yu.O., Cherepanov S.V., Holovatskyi O.V., (2021) Trends in the development of forestry in Ukraine at the present stage. Ecology and Nature Management, N.1, P.44–49.
43. Shevchuk O.M., Kovalchuk L.S., Polishchuk V.V., (2021) Natural forest resources and their rational use. Ecology and Nature Management, N.2, P.78–85.
44. State Agency of Forest Resources of Ukraine, (2025) Structure of the sector [Electronic resource]. Available at: http://dklg.kmu.gov.ua (accessed: 28.05.2025).
45. Sterba H., (2021) Understanding Forest Disturbances: A Comparative Analysis of Two Centuries of European Forest Dynamics. Springer. ISBN: 978-9400719322.
46. Temesgen H., Bettinger P., Li R., et al., (2021) Forest Sampling Designs for Inventory and Monitoring: A Statistical Primer. Springer. ISBN: 978-3030779118.
47. Tkach V.P., Buksha I.F., Vedmid M.M., (2013) Modern problems of forestry development in Kharkiv region. Forestry and Agroforestry Reclamation, Vol.122, P.3–11.
48. Vacek Z., Kneifl M., Hrůza P., et al., (2021) European Beech: A Model Species for Forestry and Conservation. Springer. ISBN: 978-3030659915.
49. Zhang J., Nielsen Å.B., Thorsen B.J., et al., (2019) Determinants of private forest management decisions: A study of Norwegian nonindustrial private forest owners. Forest Science, Vol.65, N.2, P.216–228. DOI: 10.1093/forsci/fxy037.
50. Zhu Z., Piao S., Myneni R.B., et al., (2016) Greening of the Earth and its drivers. Nature Climate Change, Vol.6, N.8, P.791–795. DOI: 10.1038/nclimate3004.
51. Zvarych V.L., Melnychuk M.D., Velychko V.V., (2015) Assessment of the activity status of forestry enterprises of Ukraine using a balanced scorecard system. Economics of Agro-Industrial Complex, N.2, P.70–76.

GROWING *EUNOMUS FORTUNEI* PLANTING MATERIAL AND USING IT IN LANDSCAPING

Tokman Volodymyr
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0002-1237-4611

Tovstukha Oleksandr
Candidate of Agricultural Sciences, Associate Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0009-0003-7999-9573

Nikolenko Maria
Master of Horticulture, Sumy National Agrarian University, Ukraine
ORCID ID: 0009-0005-4750-8455

Among the advanced powers, the state of the out-of-touch middle class is a subject of special respect. Rich plantings play a special role in weakening the negative influx of civilization. The stench permeates the natural microclimate of urban areas, takes part in the formation of the alien environment, and creates a specific image of the place. At the same time, for the improvement of urban areas, rich plantings can occupy a larger area of streets, industrial enterprises, parks and public gardens [6, 21].

Euonymus fortunei is an evergreen ornamental tea-grass native to Celastraceae R. Br., which, due to its inflexibility, durability and variety of decorative properties, finds a wide range in landscaped gardens and private areas [11, 16].

According to guesses, the taxon is valued for a whole series of aesthetic powers: it creates dense kilim plantings, you can climb along the supports with the help of dried crusts, which indicates the diversity of fertilization leaflets. The decorative effect of the bush is preserved by stretching the cane to add its unique element to the molding of the landscape middle [35].

Relevance by those. An important task is to enhance the technological process for the production of *Euonymus* gardening material, and the taxon *E. fortunei* itself, to monitor it and promote it in the improvement of the territory. This means a reduction in the species diversity of phytocenoses and an increase in their resistance to unpleasant environmental factors.

Meta-robots have been observed in the increased volumes of growth of gardening material *E. fortunei* through the path of root-hair reproduction in the soils of the spores closed to the ground and further growth in the landscaping of the covered territories.

For the sake of the above-mentioned sign, the following instructions were passed on:

- collect and analyze information to multiply the main representations no one in the genus *Euonymus*;
- look at the type of substrate at the process of creation of the root system in the gardening material of *E. fortunei*;
- evaluate the regeneration capacity of *E. fortunei* livestock during the period of their preparation;
- add infusion of Rhizopon AA poeder to the rhizogenic nature of *E. fortunei* micropagons;
- consider the viability of *E. fortunei* in green areas.

Object of work: *Euonymus fortunei* as an ornamental plant that is used for recrea-tional purposes.

Subject of research: technology of growing gardening material *Euonymus fortunei* Silver Queen and Emerald Gold.

The family *Euonymus* L. extends to the homeland Celastraceae R. Br., which has about 200 species, with about 100–120 genera and over 1300 species, expanded in tropical, subtropical and often extinct regions of the world. These are mainly trees, bushes, lianas 2–6 m high, and sometimes – branches of herbaceous plants [1, 11, 17]. Representatives of the homeland are known as decorative, medicinal and other native species.

Young pagons are often four-sided, sometimes with characteristic warty growths. The bark is gray-brown, in older trees it is cracked and flaky; it contains barnacles and bitter words that give it toxic powers. The leaves of the roses are opposite, simple, on short petioles, ovoid or eliptical in shape with a jagged edge. The leaf surface shows a fine pinnate veininess, a skinny structure, and often a sparkle. In spring, in most species the leaves turn bright red, purple or erysipelas, which means the genus is decorative [11, 15].

The flowers of the roses are small, double, collected from the umbrella-like flowers (3–9 flowers each), the calyx consists of 4–5 greenish sepals, the corolla has 4–5 yellow-green or brown petals color, 45 larvae, which are attached to a disk that exudes genetia. Plid is a capsule that opens when reached. The variety of fruits varies from rye to raspberry or red. Fruits are peeled - remove glycosides, saponins and alkaloids (evonimine, euonimoside). Cover the filling with fleshy arylus (orange and worms), which will add birds.

Mostly the plants are light-loving or shade-loving species that are resistant to dryness. It is important to grow in forests, on knots, in chagarniks, on skhila yarov. It is good to endure the cuttings, so as to make them handy for molding the livingrafts and decorative plantings.

Euonymus is an important element of the flora of the world's latitudes and has significant ecological, decorative and scientific value. Species of this genus play a role in the formation of forest ecosystems, and are promising for landscaping small areas, but will require protection and rational vigor. These species (*Euonymus nana*, *Euonymus latifolia*) are listed in the Red Book of Ukraine due to the decline of natural populations.

The most popular representatives of the genus *Euonymus* in Ukraine include: Euonymus alatus (Fig. 1-3), *Euonymus japonicas* (Fig. 4), *Euonymus europaeus* (Fig. 5), *Euonymus verrucosus* (Fig. 6-7), *Euonymus fortunei* (Fig. 8-11).

Figure 1. E. alatus [32]

E. alatus is a deciduous ornamental chagarna, a tree 1.5–3 (or up to 4) m high, which shows bright autumn leaves (Fig. 1). The pagons are almost sided, with visible corky growths in the later ones, with a “krelets” appearance. The bark is grey-brown; in older roslins it is cracked.

Figure 2. Leaves and shoots of E. alatus [32]

Leaves are opposite, simple, eliptic, 2–7 cm in length, with toothed edges. In the spring - green, in the spring - purple-red or erysipelas-crimson (Fig. 2).

The flowers of the given species are friable (up to 1 cm), greenish-yellow, light-colored, spread out in 2-3 at the axils of the leaves. The flowers are grass-cherry. The fruit bears the appearance of horny-red-red bolls, from which, when spring reaches, an orange-colored hue drips, covered with arylus (Fig. 3).

Figure 3. Flowers and fruits of E. alatus [32]

E. alatus is light-loving, frost-resistant, tolerant of small minds and short-hour shade. Growth is best on well-drained, moderately watery soils with a neutral or slightly acidic reaction (pH 6–7). Reproduces by plants, live bait, and seedlings; The plant will require stratification at +3...+5 °C for 90–120 days.

In nature it grows in forested areas of Western Asia (China, Korea, Japan). In Ukraine, it is cultivated in botanical gardens, parks and private gardens, well suited to the climatic minds of Poliss, Forest-Steppe and Pivnichnogo Steppe.

E. alatus is a valuable ornamental crop. Used: in landscape design for creating living spaces, borders, group compositions, as well as in landscaping urban areas. You are often seen in parks, for administrative purposes, and even for decorative purposes, and may not require any supervision. *E. alatus* can be an effective solitaire (besides plantings of accents), a wonderful element of living creatures or basic compositions. It is popular in landscape design for its contrast. colors and structure of nails. The plants of the named taxon contain biologically active compounds: alkaloids, saponins, glycosides. The fruits are delicious for humans, but for birds - hedgehogs are more important.

Figure 4. E. japonicus [31]

E. japonicus (Fig. 4) is an evergreen ornamental bush or small tree, 2–5 m high (sometimes up to 6 m in the wild), naturally growing in Western Asia (Japan, China, Korea). The culture, dating back to the 18th century, actively develops in landscaped areas with a dense, shiny leaf surface, a variety of decorative forms and high resistance to pruning. Roslina has a dense, rounded or branched crown, greenish or brown, smooth, mature trees and develop a gray-brown color. The leaves are simple, skinny, eliptic or egg-shaped, 3–7 cm long, 1.5–3 cm wide. The edge of the leaf blade is jagged, sometimes entire. The upper surface is dark green, shiny; the bottom one is light.

The flowers of the plants are small (up to 1 cm in diameter), greenish-white, indistinct, collected from small umbrella-like flowers, 3–9 pcs. The flower stalks are thin, up to 2 cm thick. The flowers are grass-cherry. Filled with gnats. The fruit of *E. japonicus* is a trignid capsule with a diameter of up to 1 cm, the bud is green, when it reaches a horny-orange color. The inside is dark brown, cover it with bright red or orange arilla (meat). Reaches spring (yellow-leaf fall).

E. japonicus - shaded, ale light-loving rose, good to tolerate partial shade. Gives advantage to the kindred, the good, the peaceful Volumic soils with a neutral or mild reaction. There is a short-term drop in temperature to – 15°C, but in the lower regions it can freeze, which often occurs in containers or winter shelters. It is good to tolerate gas pollution and cuttings.

It reproduces by plants, green and woody livestock, and also by nurseries. The most advanced method is live infusion (worm-lime) with vicoristic root stimulants.

E. japonicus is a popular ornamental gardening element. Vikorist is used for creating living spaces and borders, in formal plantings (topiary art), as a solitaire in park compositions and in container landscaping and interior design (zocrems in winter gardens). The species is often used for color contrasts in landscape compositions.

Figure 5. E. europaeus [34]

E. europaeus is a deciduous chagarna or a small tree 2–6 m high (sometimes up to 7 m), with a dense, spreading crown (Fig. 5). Growth is gradual, long-term (up to 50–60 years). The bush may be erect or have some bent branches, evenly sided at the transverse cut, greenish-brown. Young pagons have characteristic quadruple ribs, which is a diagnostic sign of the species. The bark is gray-brown and becomes cracked as it ages. The leaves are simple, eliptic or lanceolate, 3–8 cm long, with a serrated edge. The upper surface of the leaf is dark green, the lower surface is light green. The petioles are short (up to 1 cm). In spring, the leaves swell with a bright red or purple coloration, which makes them highly decorative. The flowers, as in the first representatives of the fungi, are greenish-white or yellowish-green, up to 1 cm in diameter, collected in 3–7 from an umbrella-like flower. There are two flowers, with several pellets. The color fades from the grass-cherry. It is consumed with komakha (entomophilous plant). The fruit is a bright, four-nestled capsule with a diameter of 1–1.5 cm, the bud is green, when reached it is erysipelas or crimson, often with several convex blades. The inside is dark brown, cover it with orange arilla (meat). The fruit reaches the cow and is often lost on the growth until winter, giving it a decorative appearance. All parts of the plant, the fruit is frozen, and peeled off when grown in the middle.

E. europaeus is a light-loving plant that grows well on rich, fresh, clayey or loamy soils. Provides superiority to vapid substrates. Dry resistance - medium, frost resistance - high (visible up to –30°C). Do not endure the dryness of water and stagnation of water. Due to its durability and inflexibility, the species is often cultivated for reforestation, strengthening of groves and layers.

It reproduces by plants, live bait and root shoots. Root shoots are actively forming at the base of old bushes, which facilitates natural vegetative renewal.

E. europaeus is resistant to most illnesses and diseases, but unfriendly minds can be attacked by euonymus milia, popelitz, and hogweed. In the middle of the disease there is widespread flatness, mildew, and bushy dew. We recommend sanitary pruning and prompt removal of weeds.

This tree is highly valued for its bright autumn leaves and decorative fruits, which are preserved until winter. These authorities often rely on landscape design for the creation of living creatures, group and solitary plantings, as well as in the forest kingdom for strengthening yars, ridges, like land reclamation, and in folk medicine, like dzherelo alkaloids and glycosides (with great care) [22, 26].

Due to the loss of fruits, the sprout is not recommended for planting in children's gardens or school areas. This is a typical representative of the flora of Europe, which plays an important role in natural ecosystems and is a valuable decorative weed for green living.

Type of expansions in Central and Modern Europe, in the Caucasus, and in Asia Minor. In Ukraine, it occurs throughout the entire territory, except for the extreme steppe zone and the high mountains of the Carpathians. Grows in forests, on knots, in chagarb thickets, ravines and river valleys. Most often it is harvested near the warehouse of broad-leaved forests (oak, hornbeam), where it creates undergrowth or clumps.

E. verrucosus is a deciduous chagarna or a small tree that has acquired its name “warty parts” through the characteristic black warty parts of growths on young branches (Fig. 6).

Figure 6. E. verrucosus [33]

The bush grows up to 2.5–3 m in height, with a rounded, densely leafed crown. In rare varieties it can reach 4 m. The width of the bush, as a rule, approximately corresponds to its height, creating a round, thick crown. The average one can reach 1.5 to 2 m in diameter [11, 17, 20].

Young shoots are thin, brown-green, densely covered with dark, corky growths - "warts". The bark becomes grey-brown or dark grey, cracked.

Leaves (Fig. 7) are opposite, eliptic or ovoid-lanceolate, 3–7 cm long along the edge of the grain-serf part, the top is pointed. The spring leaves are bright green, the intermittent leaves are dark green, and in the spring they bloom with a dark purple or fiery rye-colored bloom - *Eunomus* itself is especially decorative. The flowers of *E. verrucosus* are even smaller (5–7 mm), inconspicuous, greenish-brown, spread out in groups of 2–5 in the axillary flowers. The fruits are even decorative, but are detrimental to humans (they contain alkaloids and glycosides) [22].

Figure 7. Leaves, flowers, fruits of E. verrucosus [33]

E. verrucosus grows in Central and Contiguous Europe, throughout Ukraine, except for the most important areas of Polissya, especially in deciduous and mossy forests, in forests, skhila, near chagarnik thickets, often on vapnyak soils. To love dearly, dearly, well-drained lands.

The ecological role of this plant is important because it is an important food plant for birds, who eat fruits and spread sap. The shading is good for ventilation, which often grows near the understory. It plays a stabilizing role in biocenoses, significant ridges and disappearing erosions.

Autumn leaves and brightly colored fruits of *E. verrucosus* often grow in parks and wooded areas.

In traditional medicine, vicorism is used with caution in small doses as a transmissible and anthelmintic infection. All parts of the plant are rotten, especially the fruits - a stench can cause vomiting and a confused heart [22, 26]. Regardless of the situation, the birds themselves actively spread throughout the world, so the toxicity for them is insignificant.

I would especially like to add *E. fortunei* (Fig. 8). Ceroslina is rich river, evergreen; It has a creeping or liana-like appearance, is suitable for creating thick plantings or climbing along the supports of the wind suckers [29, 35].

Figure 8. E. fortune [35]

This *Euonymus* bears the name of the Scottish famous botanist Robert Fortune, who knew and brought the plant to England. The species has a large natural range, including many parts of China (from the sea level to an altitude of 3400 m), India, Indonesia, Japan, Korea, Laos, Myanmar, the Philippines, Thailand and Vietnam [11].

Figure 9. Shoots of E. fortunei [35]

The height of the plant depends on the molding method and reaches 0.4 to 1 m. The logs are thin, long-lasting, greenish-brown, densely ironed, filamentous, often with a ribbed surface, with long-lasting wood (Fig. 9).

The leaves of these euonymus are simple, skinny, opposite, ovoid or elliptic in shape, with a jagged edge (Fig. 10). The length of the leaf should be 2–6 cm, the color varies from dark green to lined (with yellow or white edges).

Figure 10. Leaves of E. fortunei [35]

The leaf shape is oval, leathery, shiny, with jagged edges. On top of everything, the leaf surface tends to change its fermentation throughout the growing season: in the spring it becomes horny and all winter it pleases the eyes of the ruler.

Roslin forms invisible, small greenish-white flowers, collected from small umbrella-like flowers (Fig. 11).

Figure 11. Flowers of E. fortunei [35]

The color comes out most importantly in the black lime, but the flowers do not lose their decorative value. The fruit is a round, four-sided capsule, when horny, with bright orange hues in the middle. There is a trace of the mother on the street, so that the stench is gone.

Roslina grows well, forms thick plantings, tolerates pruning well, and is easy to trim to the required shape. The building may spread along the ground or hang along the supports.

E. fortunei is most noticeable in dormouse plots (also the most beautiful). A yellow color may become darker in a pigment. The desired species will require rich, slightly moist, well-drained soils. The winter hardiness of the plant is high, with temperatures down to –25°C; In winter, the leaves may freeze, but will soon renew. Pruning must be carried out in the spring using the method of maintaining the shape.

Reproduction of representatives of the genus *Euonymus* occurs both naturally (generatively) and through vegetative methods, which is widely used in ornamental gardening and forestry. Choose a way to keep in mind the biological characteristics of the species, with the aim of developing the minds of the middle class.

This creation is not typical for wild populations. This occurs in capsule-like fruits, which, when opened, wilt the caryopsis, covered with a bright orange or erysipelas (Fig. 12).

Figure 12. Fruits and seeds of E. fortunei [35]

I'm going to get ready to go to work with the woman. The resin material is placed near the water wells of potassium permanganate. This is necessary for removing acidic and healthy seed material. Well-formed and well-formed sediment settles to the bottom of the vessel, and unclear and does not spill onto the surface. *E. fortunei* hangs near wet soil in the spring. In this case, sow and mulch with humus or straw. During the winter period, the process of stratification of the plant material begins, and *E. fortunei* emerges in the spring.

Hanging walls (Fig. 13) can be installed in the spring, otherwise they need to be stratified. For the germination of seed material, most cultivars require stratification (100 to 250 days), which is accompanied by a long period of dormancy. For this purpose, mix with soft peat or sand, and then place in a refrigerator (+2°C). The process of stratification continues throughout the winter period. Spring seeding material is hung on a plot of open ground.

Figure 13. Sowing of seeds of E. fortunei [55]

After 3 days, planting material is installed in a permanent place. In this case, during the process of replanting the plants, pinch the tops. In addition to everything, the seedlings (Fig. 14) are closed for the winter period.

Figure 14. Seedlings of E. fortunei [30]

In rozsadnytsia, vikory is rarely propagated in the present day, since it does not guarantee the preservation of decorative characters of the varieties and it is a difficult process. In nature, *E. fortunei* plants can be spread by birds and other creatures and transferred to large areas.

For the production of *E. fortunei* planting material, a vegetative propagation method is often used, which ensures the preservation of maternal signs and powers. Living is the most extensive method of planting. For this purpose, green live bait (inflight) or wood (in spring and spring) are harvested (Fig. 15). To improve the move-ment of the rooted stimulants, root solution (heteroauxin, IMC).

Figure 15. Cuttings of E. fortunei [35]

The optimal time for preparing live bait is the third decade of the worm. Prepared micropagons with a depth of 5–7 cm from two or three between nodes, it is necessary to treat them with a rooting stimulant. Micro-pagons are planted at 45° in a mixture of peat and sand. Next, water the live bait material with warm water (23°C). Live bait is covered with agrofibre or it creates a greenhouse effect, so that it takes root over a length of 4–6 rows (Fig. 16).

Figure 16. The process of growing planting material of E. fortunei [35]

Watering gardening material every day. Before the start of the growing season, the root system will be established on live bait. The appearance of new leaves on live bait indicates that regeneration of the root system has begun. Then carry out hardening of the gardening material. For the winter, cover it with compost, humus or peat (Fig. 17).

Figure 17. Shelter for winter of young seedlings of E. fortunei [30]

Pagoni, which spread along the ground, easily root at the nodes upon contact with soil. The bottom of the well-formed pagin is laid down to the ground and covered with a loose substrate or soil. In this case, do not dry the top of the pagon (with a depth of 15-20 cm). Throughout the growing season, the soil on the pagon is regularly cultivated. In the first decade of the worm, the rooting seeds emerge from the mother's bush and plant in their permanent place. The name is a method characteristic of natural propagation of *E. fortunei*, in which the growth expands, creating large bushes and can occupy large areas. Gardeners use nozzles to remove gardening material without special equipment (Fig. 18).

Figure 18. Drop-offs of E. fortunei [35]

Mature shoots of *E. fortunei* with a well-rooted root system can be propagated by plantings under the bush (particulations). This method allows for less widening, but allows you to quickly cut off a bunch of life-long lines (Fig. 19).

Figure 19. Division of the bush E. fortunei [30]

This method is used to propagate dwarf clones. In such varieties, the root system is formed finely, and root shoots appear in the skin. The alternative to this process is to dig up the stem of the tree, and then cut it into pieces with a knife or other sharp tool. When done, shorten the pagon by 50%. Remove the old gardening material and apply it to a new place. The technological operation is called not to harm the plants, and the plants are visible in a good way. Particulate the clumps of mother shoots in spring or spring.

Figure 20. Grafting planting material [30]

Chips (Fig. 20) are rarely cured, it is important for rare decorative forms and the preservation of valuable varieties. Most often they are pinched on closely related *Euonymus* species with high winter hardiness. For this purpose, take a well-formed single growth of the wild form, which will serve in the core of the wood. The cultivation must be carried out as long as there are friendly minds on the street. You can work at the end of the linden tree. In this case, cut the shield with a piece of paper on the pin and insert it at the edges on the bark of the pin (it looks like the letter "T"). Before the phase of screeching, it is necessary to remove the top of the wood chips above the shield. The brunka will create a layer that reaches up to 100 cm until the beginning of autumn.

Around the cultivars of *E. fortunei*, they create shoots that are suitable for the propagation of decorative forms of plants. Young plants are carefully dug up, and then replanted in a new place and mature in the face of intense sedative changes.

Vegetative methods (living, planting) guarantee identity with the mother plant, the ability to create decorative forms, which is widely used in ornamental gardening.

The most promising for practical cultivation in the minds of landscaping and ornamental gardening are vegetative methods of propagation, growing livestock and plantings, which will ensure the mass removal of planting material and conservation of characteristic decorative authorities.

Figure 21. Harvesting of cuttings material [own photo]

Figure 22. Cuttings of E. fortunei [own photo]

An experimental part of the qualified work of vikonan in the minds of a sporuda closed to the ground in the initial laboratory of Landscape Design. At the root of the gardening material for root propagation of *E. fortunei*, the stem micropagons were harvested at a depth of approximately 6-8 cm (Fig. 21-22). Live bait material was kept in water for 1 year.

The temperature during the hour fluctuated between +18 - +26°C, and the humidity was 60-70%. For the leather version, 80 pieces were prepared. live bait For livestock, mother plants of *E. fortunei* (Silver Queen and Emerald Gold) were harvested for up to 5 years. The substrate is made up of mixed peat and river sand. The depth of application to the gardening material was 2 - 4 cm.

Poshukova's work was carried out in three directions:

1. Analysis of the term baiting on the process of coregenesis in stem baitfish *E. fortunei*.
2. Revealing the influx of form features on the uniqueness of stem micropagons.
3. Infusion of Rhizopon AA poeder to renovate the root system of live *E. fortunei*.

The experimental design included variations, factors such as the type of substrate,
terms of life, the form and characteristics of the auxin nature (Rhizopon AA poeder).

Experimental research was carried out on the offensive scheme:

Factor A – type of substrate: 1) forest soil; 2) sand; 3) peat (control). Factor B – term livestock: 1) control (10.04); 2) 10.05; 3) 10.06; 4) 10.08. Factor B – form features: 1) control (Silver Queen); 2) Emerald Gold. Factor G – semi-auxin nature: 1) Rhizopon AA poeder; 2) control (water).

The treatment of gardening material with physiologically active chemicals was carried out according to the instructions for the plant (Fig. 23).

Figure 23. Treatment of cuttings with root formation stimulator [own photo]

The work was condensed to the methods of efficient propagation of ornamental and flowering plants in the Botanical Garden of Ukraine [14]. The results were processed using additional special programs.

Reproduction of plants is a biological feature of a living organism, in the process of which new individuals are formed. The essence of it lies in the ability of the body to form similar parts to itself. There are two ways of propagating growing organisms: plant and root (vegetative). The basis of root-hair creation is the regenerative ability of the body to renew the waste of organs. For the minds of vegetative propagation, the new generation is formed from somatic tissues. It should be emphasized that signs of decline are preserved in everyday life [3, 9, 12, 18].

In addition to everything, vegetative propagation is actively developed in nurseries for the production of gardening material with characteristic features (highly decorative crown, planted with leaf shape), such as for plant reproduction on the plots often transmitted or not transmitted [2, 25].

Reproduction of plants with the help of stem lifers is a common method of root propagation. When living, the integrity of the plant organism is destroyed, and for the gardening material it is necessary to create drains for the regeneration of damaged organs [19, 25].

One of the important changes for the renewal of the root system in mikropagons is a substrate [5, 10], which is characterized by optimal agrophysical characteristics (Table 1).

The results of the experimental investigation show that the minimal indicator of the root-creative nature of the *E. fortune* microorganisms was recorded in the variant where the field soil was vicorized. The maximum value of rhizogenesis was observed in the variant where peat was vicorized.

Table 1. Effect of substrate type on rhizogenic capacity of *E. fortunei* cuttings

Experiment option	Decorative form	Restorative capacity, %	± to control
Field land	Silver Queen	62	- 36
	Emerald Gold	59	- 37
Sand	Silver Queen	87	- 11
	Emerald Gold	89	- 7
Peat (control)	Silver Queen	98	-
	Emerald Gold	96	-

At the same time, there was a difference between the options, and it is important that vegetative propagation of decorative forms of *E. fortunei* must be carried out in peat.

Analysis of the results of experimental testing to determine whether the type of substrate influences the regeneration capacity of livestock in monitored cultivars.

The results of the research into the regeneration capacity of *E. fortunei* livestock are presented in Table. 2.

For the livestock on 10.05 and 10.06, the indicator of regenerative yield was not likely to vary under control, but during the livestock on 10.08, a change in the creative yield was recorded.

Table 2. The influence of the term cuttings on the process of adventive rhizogenesis

Option	Decorative form	Restorative capacity, %	± to control
Control (10.04)	Silver Queen	93	-
	Emerald Gold	95	-
10.05	Silver Queen	96	+ 3
	Emerald Gold	98	+ 3
10.06	Silver Queen	95	- 1
	Emerald Gold	98	0
10.08	Silver Queen	48	- 48
	Emerald Gold	41	- 57

During the investigation, it was revealed that the period of preparation of gardening material coincides with the processes of creation of the root system in micro-plants of decorative forms of *E. fortunei*. The early stages of preparing live bait form the minds to the probable improvement of the regenerative capacity of them, the lower development new agrotechnical input at a later date.

The enhanced regenerative properties of live bait material are supported by phytohormones (biologically active substances) [28]. In this case, they activate the processes of establishment and growth of roots, and also ensure faster rooting in the stem microorganisms of plant-based organisms that are difficult to root [13].

Due to its physiologically active nature, in the process of propagation of decorative forms, *E. fortunei* creates a very friendly mind by controlling the processes of formation of the root system of gardening material (Table 3).

The results of the investigations made it possible to reveal that the presence of physiologically active compounds does not affect the rhizogenic growth of *E. fortune* microorganisms. In the shock variant, the value of the root-creating yield of live bait was in the range of 99-100%, which was 1-4% higher than in the control. Please note that the root system of live bait fish in the previous version was more disturbed.

Thus, the harvesting of live bait material Rhizopon is a clear indication of a well-developed garden material.

Table 3. The influence of Rhizopon AA poeder on the reproduction process of the root system

Option	Decorative form	Restorative capacity, %	± to control
Rhizopon	Emerald Gold	100	+ 4
	Silver Queen	99	+ 1
Control (water)	Emerald Gold	96	-
	Silver Queen	98	-
HIP $_{05}$		7,53	

E. fortunei is one of the most popular plants for landscaping and decoration of garden plots and garden areas [7-8, 20]. In European countries, you can see it on the streets, in public gardens and in private gardens [15, 24].

The taxon is predicted to be similar to China [23].. Vin vikorist is found in the green dominion, and today it is found in gardens of various climatic zones. Agricultural technology for its cultivation is fundamentally different from other Euonymus cultivars. This chagarnik is slanky. In addition to everything, the taxon belongs to evergreen crops, which grow in high latitudes [23]. There are a number of decorative forms (Fig. 24), which vary with the color of the leaves, and harmoniously decorate your pot or mixborder.

Figure 24. Leaves of E. fortunei [29]

The representatives of the gardening and park government appreciated the decorative power of this type and used it for the improvement of public gardens and parks. Plant *Euonymus* in effective single plantings (Fig. 25).

Figure 25. Saltwater plantations of E. fortunei [29, 35]

E. fortunei can be grown in the yakost of ground-covered growths under the crowns of trees (Fig. 26). It is difficult for other types of plants to grow, but it will be better growth in the minds of light deficiency, as well as clones from lined leaves. At the same time, the decorative forms of *Euonymus* are transformed from ground-covering crops in liana-like (coils), but not very tall. For optimum results, plants of these varieties can reach 200 cm in height (Fig. 27).

Figure 26. E. fortunei [29]

Figure 27. E. fortunei in vertical landscaping [35]

On the right, *E. fortunei* looks highly decorative not only in solitaire plantings, but also in group ones. They can be used to form living gardens, or even borders (Fig. 28), with which *Euonymus* looks attractive both in summer and spring.

Figure 28. Hedge E. fortunei [35]

Euonymus requires periodic pruning, which is why the bush begins to intensely gel, which adds to its decorative appearance. Shaping pruning makes it possible to create unique topiaries (Fig. 29).

Figure 29. Topiary figures of E. fortunei [29]

Container gardening (Fig. 30) is a current and effective method of improving urban space, which is becoming increasingly popular in the minds of the urban middle surrounded by space. One of the promising plants for this type of landscaping is *E. fortunei*.

Figure 30. Container culture of E. fortunei [35]

Container culture facilitates the growth and development of plants, preserving their decorative properties throughout the growing season.

Surrounding everything, *E. fortunei* grows like a room-balcony plant. Therefore, winters are good at temperatures above +20°C.

The decorative form of *E. fortunei* goes well with other types of growths in rockeries and alpine hills (Fig. 31). Vin looks great in compositions with coniferous cultivars, as well as other chagarnas.

Figure 31. E. fortunei in garden design [35]

E. fortunei decorates the base of bushes and trees, hanging in front of conifers (*Thuja, Picea, Juniperus, Taxus*) (Fig. 32).

Figure 32. E. fortunei in landscaping [35]

E. fortunei shows a slight deficiency of light, but its pockmarked form is better suited to grow on the dormouse plot and the leaves are more colorful. Do not plant it in lowlands or plots with nearby groundwater deposits. Vin will be pleased with its active growth on native soil with a neutral reaction of the middle ground. Crushed stone is poured onto the bottom of a garden measuring 50x50 cm to remove excess water, and then covered with fertile soil. On acidic soils, add 200 g of vapnyak material.

Planting material is better to plant in spring, but autumn is also possible planting. The soil is compacted around the seedling, intensively watered and mulched with peat or compost. At the same time, within 10-15 days after planting, the soil moisture is controlled.

Euonymus does not vitrify the soil, but it is not necessary to sacrifice the soil for the minds. During periods of regular rainfall, water rises and the excess moisture in the soil negatively affects the development of the root system.

During the growing season, *Euonymus* survives several times: the first - add nitrogen fertilizers in the spring, complex vicorous fertilizers, and stagnate phosphorus and potassium fertilizers in the spring. In addition, in the spring, add compost at a rate of 3-4 kg/m² of near-burning stake.

Conclusions

It was discovered that the root-creating properties of *E. fortunei* microorganisms are infused with a substrate during the preparation of gardening material. The most suitable substrate for the rooting of live baits of the target taxon is peat. With this, the indicator of rhizogenic content became 96-98%. For root-haired propagation of *E. fortunei*, it is necessary to completely sap live bait with a stretch of cherry-worm. The indicator of the creative output of micro-panels in the control variant was between 93-95%, and in the last variant (10.08) it was 48-57% less. Treating the gardening material with a root stimulant (Rhizopon) promoted the development of the root system. Representatives of *E. fortunei* form high decorative plants in solitary and group plantings and associate with other taxa. The medical diversity of the vicor of *E. fortunei*, which contains its unique element in the mold of the absent medium.

REFERENCES

1. Andreev V. N., (2015) Dendrology. Pokritonasinny. Kherson, 123 p.
2. Balabak A F., (2003) Korenevlasne propagation of small-growing fruit and berry crops: monograph. Uman: Operational Polygraphy, 109 p.
3. Bilous V. I., (2005) Ornamental gardening: handyman. Uman, 296 p.
4. Boyko I. M., (2016) Decorative gardening. Kiev: Lira-K, 320 p.
5. Vasilenko S. P., (2014) Fundamentals of growing ornamental plant gardens. Kiev: Center for Educational Literature, 248 p.
6. Vlasyuk S. G., Bondarenko A. O., (2020) Fundamentals of decorative gardening. *Gardening and viticulture*. Kiev, P. 351-365.
7. Glazachev B. O., Pushkar V. V., (2006) Handbook of the Master of the Green Dominion. Kiev: Tekhnika, 184 p.
8. Davidova O. E., Mokrinsky V. M., Veshitsky V. A., Sirik V. V., Yavorovsky P. P., (2007) Gardening and plant material for green living and forestry, adaptations to the stressed minds of dowkill. Kiev: "Komps", 200 p.
9. Elenevsky A. G., Solovyova M. P., Tikhomirov V. M., (2004) Botany. Taxonomy of growing plants. Kiev: Academy, 432 p.
10. Zhurachak R.V., (2013) Fundamentals of agricultural technology of ornamental plants. Chernivtsi: Ruta, 183 p.
11. Kalinichenko O. A., (2003) Decorative dendrology: education. manual. Kyiv: School, 199 p.
12. Klimenko Yu. O., (2012) Propagation of decorative plants. Uman: Sochinsky, 140 p.
13. Kobiletska M. S., Terek O. I., (2017) Biochemistry of roslin: beginning. posb. Lviv: LNU im. Ivana Franka, 270 p.
14. Kolesnichenko O. V., Slyusar S. I., Yakobchuk O. M., Kolesnichenko, O. V., (2008) Methodological recommendations for the propagation of ornamental plants in the villages of the Botanical Garden of the NUBIP of Ukraine. Kiev: NUBiP of Ukraine, 55 p.
15. Kondratyuk O. A., Trokhimenko N. M., Parkhomenko L. I., (2005) Arboretum of Ukraine: wild plants and cultivated village plants. Part II. Kiev: Phytosociocenter, 716 p.
16. Kostyuk I. B., (2009) Fundamentals of decorative gardening. Kiev: Agrarian Science, 220 p.
17. Kokhanovsky V. M., Melnik T. I., Kovalenko I. M., Melnik A.V., (2020) Decorative dendrology: navch. pos_b. Sumi: FOP Tsyoma S.P., 263 p.
18. Kravets M. I., (2011) Roslin propagation by vegetative method. Lviv: Kamenyar, 168 p.
19. Krivko N. P., (2018) Workshop on growing garden crops. Kiev: Lan, 288 p.
20. Kuznetsov S. I., Levon F. M., Pushkar V. V., (2013) Assortment of trees, bushes and vines for landscaping in Ukraine. Kiev: Komprint, 256 p.
21. Kucheryavy V. V., Kucheryavy V. S., (2019) Landscaping of the populated area. Lviv: New world - 2000, 224 p.
22. Lysyuk R. M., Shlyakhta Ya. M., (2014) Healing woody plants: education. manual. Kyiv: Knowledge. 165 p.
23. Marynych I. S., Pushkar V. IN., (2007) Decorative dendrology: teaching-method. manual. Kyiv: DAKKKiM, 168 p.
24. Nechitailo V. A., Badanina V. A., Gritsenko V. V., (2015.) Cultural cultures of Ukraine. Kiev: Phytosociocenter, 351 p.
25. Opalko O. A., Balabak O. A., (2001) Growth before root genesis - adaptive response of genotypes of garden plants. *Newsletter of the UDAA*. Special. VIP No. 1–2, P. 65–66.
26. Salamon I., Hrytsyna M., (2019) Veterinary medicine and the use of medicinal plants. *Scientific Bulletin of LNUVMBT named after S. WITH. Gzytskyi*, T. 21, № 94, P. 121-126.
27. Davies P. J., (2004) Plant hormones biosynthesis, signal transduction action. Dordrecht; Boston; London: Kluwer Academic publisher, 750 p.
28. Srivastava L. M., (2001) Plant Growth and Development: Hormones and Environment. 772 p.
29. Euonymus fortunei [Electronic resource]. Access mode: URL: https://fermer.blog/bok/sad/beresklet/beresklet-vidy/15582-beresklet-forchuna.html
30. Fortune's euonymus in greenery [Electronic resource]. Access mode: URL: https://floristics.info/ua/statti/sadivnitstvo/2424-bruslina-posadka-i-doglyad-rozmn ozhennya
31. Euonymus [Electronic resource]. Access mode: URL: https://perebus.com.ua/beresklet-forchun-sorti-foto-i-opis-posadka-i-doglyad/
32. Euonymus [Electronic resource]. Access mode: URL: https://perebus.com.ua/wp-content/uploads/beresklet-5.jpg
33. See the euonymus [Electronic resource]. Access mode: URL: https://landshaft.info/uk/beresklet/78-euonymus-fortunei-silver-queen?srsltid AfmBO
34. See euonymus [Electronic resource]. Access mode: URL: https://agro-landing.com.ua/ua/p645215091-sazhentsy-bereskleta-forchuna.html?srsltid=AfmB
35. Euonymus fortunei in greenery [Electronic resource]. Access mode: URL: https://perebus.com.ua/beresklet-posadka-i-doglyad-rozmnozhennya-likuvalni-vlastiv

PECULIARITIES OF GROWING *PINUS SYLVESTRIS L.* IN THE NORTHEASTERN FOREST-STEPPE OF UKRAINE

Sergii Butenko
Doctor Phd, Lecturer of the Department, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0002-9925-3029

Scots pine (*Pinus sylvestris* L.) is one of the most important forest-forming species in Ukraine, occupying more than 35% of the country's coniferous forest area. In the conditions of the Northeastern Forest-Steppe, this species plays a key role in the formation of highly productive forest stands, the performance of ecological functions, and the provision of valuable timber for forestry.

However, climate change, increasing anthropogenic pressure, and the need to intensify reforestation require improvements in pine cultivation technologies. The relevance of the study is обусловлена the need to increase the efficiency of forest cultivation activities, particularly through the introduction of modern technologies for growing planting material with a closed root system, optimization of planting schemes, and improvement of care for young stands.

The practical significance of the work lies in the development of scientifically substantiated recommendations for growing *Pinus sylvestris L.* under the conditions of the Sumy forestry enterprise, which will contribute to improving the quality and productivity of created forest plantations.

The aim of the study is a comprehensive investigation of the peculiarities of growing *Pinus sylvestris* L. in the conditions of the Northeastern Forest-Steppe of Ukraine and the development of recommendations for optimizing the technology of creating pine plantations.

Research objectives: To analyze the biological characteristics and experience of growing *Pinus sylvestris* L. under different forest site conditions. To characterize the natural and climatic conditions as well as forest inventory indicators of the forest fund of the Sumy forestry enterprise. To study the technology of creating pine plantations in the enterprise and determine the survival rate indicators of different types of planting material. To investigate the growth dynamics of pine plantations aged 5, 10, and 15 years in fresh subor conditions. To assess the sanitary condition and productivity of pine stands of different ages. To develop scientifically grounded recommendations for optimizing the cultivation technology of *Pinus sylvestris* L. in the conditions of the Sumy forestry enterprise.

Object of the study – the process of growth and formation of artificial pine stands in the conditions of the Northeastern Forest-Steppe of Ukraine.

Subject of the study – peculiarities of cultivating *Pinus sylvestris* L. plantations created using planting material with different types of root systems under the conditions of the Sumy forestry of the State Enterprise "Forests of Ukraine".

Research methods. The study employed a комплекс of general scientific and specialized methods: analytical – for studying literature sources and regulatory frameworks; field – for collecting primary data on sample plots; forest inventory – for determining forest mensuration indicators according to the methodology of DSTU 4633:2006; statistical – for processing experimental data and assessing the reliability of results using Student’s t-test; comparative – for comparing indicators of plantations of different ages and types of planting material; graphical – for visualizing the obtained results.

Scientific novelty of the obtained results. For the first time under the conditions of the Sumy forestry enterprise, a comprehensive comparative study of survival rate, growth, and condition of pine plantations created with planting material having open and closed root systems was carried out. The relationship between the type of seedling root system and survival indicators in different forest site conditions was proven. Patterns of growth dynamics and changes in the preservation of pine stands aged from 5 to 15 years were established.

Scientific and methodological approaches to selecting optimal planting schemes depending on forest site conditions and planting material quality were improved.

Practical significance of the obtained results. The developed recommendations for optimizing the cultivation technology of *Pinus sylvestris* L. can be implemented in the production activities of the Sumy forestry enterprise and other forestry enterprises of the Northeastern Forest-Steppe of Ukraine. The research results make it possible to increase plantation survival rates to 93–95%, reduce costs for replanting and agrotechnical care, and ensure the formation of highly productive stands of I–II site quality classes. The economic effect of using containerized planting material is about 2850 UAH/ha due to reduced replanting needs.

Botanical Characteristics and Taxonomic Position of *Pinus Sylvestris* L.

Scots pine belongs to the pine family (Pinaceae) and the genus *Pinus*, which includes more than one hundred species distributed mainly in the temperate zone of the Northern Hemisphere. The taxonomic position of the species reflects its evolutionary relationships with other representatives of gymnosperms, which allows for a better understanding of the biological characteristics and adaptive mechanisms of this tree species [25].

The morphological features of Scots pine are characterized by significant variability depending on growing conditions. Trees can reach heights of 20–40 meters; however, under unfavorable conditions, particularly on poor soils or in mountainous areas, their size is considerably smaller. The crown in young trees has a conical shape, but with age it acquires a characteristic umbrella-like or rounded form. It should be noted that these changes are associated not only with age-related characteristics but also with lighting conditions and stand density.

The needles are arranged in pairs on shortened shoots, with lengths ranging from 4 to 7 cm. Their color varies from bluish-green to dark green depending on age, climatic conditions, and mineral nutrition. Needles remain on the tree for 2–3 years, after which they are naturally replaced. The bark also shows age-related variability: in young trees it is thin and grayish-red, while in older trees it becomes thick, deeply fissured, with a characteristic reddish-brown color [16].

The generative organs of Scots pine have a structure typical of gymnosperms. Male cones are located at the base of young shoots, while female cones develop at the tips of current-year shoots. Pollination occurs in May–June, but seeds mature only in the second year after pollination. Cones are elongated-ovoid, 3–7 cm long, and at maturity acquire a grayish-brown or reddish-brown color. The seeds are small, with well-developed wings that enable effective wind dispersal over considerable distances, sometimes up to several hundred meters from the parent tree [4].

The root system of Scots pine is characterized by high plasticity, allowing it to grow successfully on soils with different mechanical compositions and moisture conditions. On deep, well-drained soils, a strong taproot develops, which can penetrate to depths exceeding 5–6 meters. In cases of shallow groundwater or dense underlying layers, the root system becomes more superficial, with well-developed lateral roots. This assumption is supported by numerous studies of pine growth under various forest site conditions, although precise data on root penetration depth in each specific case remain insufficient [29].

Natural Distribution Range and Ecological Characteristics of The Species

The natural range of Scots pine covers a vast territory from Scotland in the west to the Sea of Okhotsk in the east, from the Arctic Circle in the north to the mountainous regions of Spain, Italy and the Balkan Peninsula in the south. Such a wide range indicates the high ecological plasticity of the species and its ability to adapt to various climatic conditions. In Ukraine, Scots pine is found mainly in the Polissya zone, where it forms both pure and mixed stands, as well as in the Carpathians, where it grows at an altitude from the foothills to the upper border of the forest belt. The ecological amplitude of the species with respect to climatic factors is extremely wide. Scots pine can withstand winter temperatures down to –40 to –45°C, making it one of the most frost-resistant tree species. At the same time, it is capable of growing under the arid conditions of the steppe zone, although its growth slows and productivity decreases under such conditions. Optimal conditions for pine growth are areas with an annual precipitation of 500–700 mm and an average annual temperature of 5–8°C [2].

Light requirements are among the most characteristic ecological features of the species. Scots pine is a light-demanding species, which determines its competitive ability in different forest communities. At a young age, seedlings and natural regeneration can tolerate some shading; however, for normal growth and development, they require full or at least sufficient light. This explains why, in mixed stands, pine is often outcompeted by more shade-tolerant species such as spruce or beech if appropriate silvicultural measures are not applied.

The soil requirements of Scots pine are relatively low, allowing it to colonize areas with poor sandy or rocky soils where other tree species cannot grow successfully. Based on comparative analysis, the most favorable conditions are fresh and moist sandy loam and loamy soils with a well-developed humus horizon. However, pine is capable of growing even on dune sands and peatlands, although its productivity is significantly lower under such extreme conditions [8].

The species also demonstrates a wide tolerance to soil moisture. Scots pine can grow both on dry and excessively moist soils, including raised bogs. However, it grows best on fresh, well-drained soils, where an optimal balance of water and air is maintained. Under such conditions, trees develop a strong root system, show high productivity, and exhibit resistance to adverse factors. On waterlogged soils, pine develops a superficial root system, which reduces wind resistance and makes it more susceptible to windthrow.

Soil acidity has some, though not critical, importance for pine growth. The best growth performance is observed on slightly acidic to acidic soils with a pH of 4.5–6.5. On alkaline soils, pine grows хуже, and needle chlorosis is often observed due to impaired iron nutrition. This assumption requires further confirmation regarding the specific mechanisms of the influence of acidity on physiological processes; however, practical forestry experience confirms better results on acidic soils [5].

Silvicultural and Biological Properties of Scots Pine

The growth rate of Scots pine depends on the age of the trees and site conditions, making this species attractive for artificial forest cultivation. At a young age, approximately up to 10–15 years, height increment is relatively low and amounts to 20–30 cm per year. After this period, a phase of intensive growth begins, during which annual increments can reach 50–70 cm. Maximum growth intensity is observed at the age of 20–40 years, after which it gradually decreases. The total lifespan of Scots pine can reach 300–400 years; however, in forestry practice, the rotation period usually ranges from 80 to 120 years depending on the purpose of the stands.

Scots pine begins to bear cones relatively early: in open stands, the first cones may appear at the age of 15–20 years, whereas in dense stands, the onset of seed production occurs later, at 25–35 years. Abundant seed crops do not occur annually but with a periodicity of 3–5 years, which is related to weather conditions and biological rhythms of the species. In intermediate years, some cones are also formed, but in significantly smaller quantities. Pine seeds are characterized by high viability and germination capacity, which, under proper storage conditions, can be maintained for several years [17].

The regenerative capacity of Scots pine is realized mainly through seed regeneration, as this species lacks the ability to regenerate vegetatively. Natural regeneration occurs most successfully on mineralized soils, where seeds can directly contact the mineral layer. On sites with a thick litter layer or dense grass cover, natural regeneration is hindered, requiring specific silvicultural measures. It should be noted that young pine seedlings are particularly sensitive to competition from herbaceous vegetation during the first years of life [9].

Resistance to pests and diseases is one of the criteria determining the economic value of a tree species. Scots pine is relatively resistant to most pests and pathogens; however, under certain conditions, it may be affected by various organisms. Among the most dangerous pests is the pine sawfly, which during outbreak years can completely defoliate large areas. Among diseases, fungi causing needle cast (especially in young stands and forest nurseries) pose the greatest threat [37].

The fire hazard of pine stands requires special attention in forest management. Scots pine belongs to species with relatively low fire resistance, especially to surface fires that damage the thin bark in the lower part of the stem and the root system. Needle litter and dry herbaceous vegetation create highly flammable materials that contribute to the rapid spread of fire. However, mature trees with thick bark in the upper part of the stem can withstand low-intensity surface fires without significant damage.

The economic importance of Scots pine is determined by the high quality of its wood and its wide range of applications. Pine wood is characterized by straight grain, sufficient strength, ease of processing, and durability, making it a valuable material for construction, furniture production, and other industries. In addition to timber, pine is a source of resin, from which rosin and turpentine are produced. Pine-dominated forests also have recreational value due to the favorable microclimate created by the release of phytoncides [44].

Experience in The Establishment and Cultivation of Pine Plantations

The history of artificial cultivation of Scots pine in Ukraine spans more than a century, during which considerable experience has been accumulated in the establishment and management of pine plantations. The first large-scale plantings of pine on sandy soils of Polissya began in the late 19th century with the aim of stabilizing mobile sands and restoring forest cover. Since then, technologies for establishing forest plantations have been continuously improved, taking into account both positive experiences and past shortcomings.

The choice of planting material type has a significant impact on the success of pine plantation establishment and their subsequent development. Traditionally, bare-root seedlings aged 2–3 years, grown in open-ground forest nurseries, were used. In recent decades, the use of containerized seedlings with a closed root system, grown in specialized containers, has become increasingly widespread. Based on comparative analysis, it can be concluded that containerized seedlings demonstrate higher survival rates and initiate active growth earlier after planting [22].

Studies on the growth and condition of pine plantations established with different types of planting material, conducted in the Southeastern Forest-Steppe of Ukraine, have revealed certain patterns. Plantations established with containerized seedlings were characterized by higher plant survival, especially in the first years after planting. At the same time, growth rates during the first 3–5 years were approximately similar regardless of the type of planting material. This assumption requires further confirmation over longer observation periods; however, the available data allow recommending the use of containerized seedlings on sites difficult for afforestation [12].

Soil preparation prior to the establishment of forest plantations includes a комплекс of measures aimed at improving conditions for seedling survival and growth. On former agricultural lands, full plowing or disking is usually carried out to eliminate herbaceous vegetation and improve soil physical properties. On recent clear-cuts, both full and partial soil preparation methods may be applied, including the creation of furrows or planting spots. The choice of method depends on many factors, including soil texture, moisture conditions, site clutter, and the technical capabilities of the enterprise.

Planting schemes are determined by the intended purpose of the future stands and site conditions. For the establishment of highly productive stands, schemes of 2.5 × 0.7 m or 3 × 1 m are most commonly used, providing an initial density of 4,000–5,000 plants per hectare. Under difficult site conditions or when establishing protective plantations, higher planting densities may be applied. It should be noted that excessively dense plantations require early thinning, while overly sparse planting may lead to stem defects due to insufficient competition among trees [38].

Maintenance of pine plantations in the first years after establishment includes both agrotechnical and silvicultural treatments. Agrotechnical measures are aimed at controlling herbaceous vegetation that competes with the plantations for water and nutrients. Depending on the intensity of grass development, 2–3 treatments are carried out annually for 3–5 years until crown closure. Silvicultural treatments begin when the plantations reach a height of 2–3 meters and involve the removal of undesirable tree species and the formation of optimal stand density [11].

Modern Reforestation Technologies and Regulatory Framework

The technological process of growing pine planting material in modern forest nurseries is based on the application of scientific achievements in forest seed production and seedling cultivation techniques. A key stage is obtaining high-quality seeds from selectively chosen stands, which makes it possible to improve the hereditary traits of future plantations. Seeds are collected from a permanent forest seed base, which includes plus stands, plus trees, and seed orchards [13].

Pre-sowing seed preparation includes several operations aimed at improving germination and seed vigor. Pine seeds undergo stratification—keeping them in a moist state at low temperatures for 1–2 months. This method accelerates and synchronizes germination. Studies have shown that seeds of different colors may have different germination capacities; therefore, color sorting allows the selection of the highest-quality seeds for sowing [4].

Containerized seedling cultivation is becoming increasingly widespread due to its advantages over traditional methods. The use of special trays with cells filled with peat-based substrates creates optimal conditions for root system development. Seedlings can be grown in greenhouses with controlled conditions, allowing standard planting material to be obtained within a single growing season. It should be noted that container technologies require significant initial investment; however, they ensure higher quality and ease of use of planting material [21].

The use of biological preparations in the cultivation of planting material is aimed at increasing plant resistance to adverse factors and stimulating growth. Studies on the effects of bio-organic compositions on pine seedlings have shown positive results. In particular, preparations based on basidiomycetes and nanoparticles contributed to improved development of both root systems and aboveground parts of plants. This assumption requires further confirmation regarding the economic feasibility of large-scale application of such preparations [35].

The regulatory framework for forest cultivation activities in Ukraine is represented by a комплекс of legislative acts and normative documents regulating forest regeneration processes. The main legislative document is the Forest Code of Ukraine, which defines the legal, economic, ecological, and organizational principles of sustainable forest management. The Code establishes principles for sustainable forestry development, biodiversity conservation, and ensuring ecological functions of forests [23].

The Instruction on the design, technical acceptance, accounting, and quality assessment of forest cultivation objects regulates technological processes for establishing forest plantations and requirements for their quality. The document defines evaluation indicators for forest cultivation activities at different stages, including the selection of plantation type, soil preparation, planting of seedlings, and maintenance. According to the instruction, forest plantations are considered successfully established if the survival rate of the main species is at least 85%, and the condition of plants is assessed as satisfactory or better [31].

The State Forest Management Strategy of Ukraine until 2035 defines long-term priorities for the development of forestry in the context of modern challenges. The strategy предусматриває the implementation of European forestry standards, strengthening forest protection, conserving biodiversity, and adapting to climate change. A separate focus is placed on the modernization of forest nurseries and the introduction of modern technologies for growing planting material. Based on comparative analysis, it can be concluded that the implementation of the strategy will contribute to increasing the efficiency of reforestation and improving the quality of established plantations [32].

General Characteristics of The Sumy Forest District of SE "Ukraine's Forests"

The state enterprise "Ukraine's Forests" operates as one of the largest state forestry companies in Europe, responsible for the protection, management, afforestation, reforestation, and timber harvesting across extensive areas of the country. The enterprise was established in 2022 through the reorganization of existing state forestry structures, which allowed for the optimization of forest fund management and increased efficiency in the use of forest resources. SE "Ukraine's Forests" includes numerous branches located in different regions, among which the "Northern Forest Office" branch unites the forests of the Sumy and Chernihiv regions [4-1].

The Sumy Forest District was created on the basis of the former state enterprise "Sumy Forestry," whose history dates back to 1936. Over nearly nine decades, the enterprise has undergone a complex development path influenced by changing economic conditions and approaches to forest management. The initial period was characterized by a predominance of exploitative functions, typical for the Soviet era. However, after Ukraine gained independence in 1991, priorities gradually shifted—emphasizing the balanced use of forest resources, biodiversity conservation, and ensuring the ecological functions of forests.

The organizational structure of the Sumy Forest District includes four forest units: Mohrytske, Nyzivske, Pishchanske, and Sumy, each performing specific functions in managing the allocated forest territories. The enterprise also includes production units: a timber processing workshop conducting primary processing of harvested raw materials; a souvenir workshop producing wooden goods for retail; a primary forest nursery supplying planting material for reforestation; a fire-chemical station responsible for forest fire prevention and suppression; and a machine-tractor fleet providing the necessary equipment for forestry operations [38-1].

The total area of forest fund lands permanently allocated to the Sumy Forest District is 26,687.4 hectares, of which 24,434.8 hectares are covered by forest vegetation, corresponding to a forest cover rate of approximately 91.6%. The distribution of forests by functional purpose reflects current priorities of multi-purpose forest use. Forests designated for conservation, scientific, and historical-cultural purposes occupy 4,058.0 hectares, or 15.2% of the total area. The largest share—21,109.4 hectares, or 79.1%—consists of recreational and wellness forests, mainly located in the suburban areas of the city of Sumy and other settlements. Protective forests cover 1,520.0 hectares, or 5.7%, performing anti-erosion and water protection functions along rivers and on slopes [27-1].

The main activities of the Sumy Forest District cover the entire range of forestry operations. Reforestation is carried out both artificially, through the planting of seedlings and saplings, and naturally, by preserving undergrowth and creating conditions for natural seeding. Logging activities include thinning, sanitary felling, and final harvest within the approved calculated cutting areas. Forest fire protection is ensured through preventive measures, patrolling, and rapid response to fire outbreaks. Protection against pests and diseases is carried out using biological methods and, if necessary, chemical treatments. In addition to production functions, the forest district actively cooperates with local communities and educational institutions, organizing school excursions, educational programs, and activities aimed at raising public ecological awareness.

Natural and Climatic Conditions of The North-Eastern Forest-Steppe of Ukraine

Sumy Oblast is located in the north-eastern part of Ukraine and occupies an area of 23.8 thousand square kilometers, which accounts for approximately 3.9% of the country's territory. The region's geographical position determines its unique natural conditions, encompassing parts of two physico-geographical zones: Polissya in the north and the Forest-Steppe in the south. This transitional position creates favorable conditions for forest vegetation development and allows for the cultivation of a wide range of tree species. The oblast borders Kharkiv and Poltava Oblasts to the south, Chernihiv Oblast to the west, and Kursk, Belgorod, and Bryansk regions of the Russian Federation to the east and north [14-1].

The climate of the region is classified as moderately continental with elements of moderate humidity, characterized by relatively mild winters and warm summers. The average annual air temperature ranges from 6.6 to 6.8 °C; however, over the past century, a trend of increasing temperature has been observed—rising by approximately 1.5 °C, consistent with global climate change. The winter period is characterized by average monthly temperatures from −5 to −8 °C in the coldest month (February), although more severe frosts down to −25 to −30 °C may occur during Arctic intrusions. Summer temperatures average 20–25 °C, with a maximum of around 25.8 °C in July, creating favorable conditions for active growth of woody plants [17-1].

Precipitation patterns exhibit marked seasonal variability, with a predominance of summer rainfall. The average annual precipitation ranges from 550 to 675 mm, of which about 64% falls during the warm period from April to October. The highest rainfall occurs in July (up to 80–90 mm), while the lowest occurs in February (around 30–35 mm). In recent decades, precipitation regimes have shown significant variability due to climate change. For example, the winter of 2019–2020 was characterized by anomalously low precipitation—only 50–70% of the long-term average. The growing season, with temperatures above 10 °C, lasts 200–210 days, sufficient for the successful growth of both coniferous and deciduous tree species [22-1].

The relief of the territory was shaped by ancient geological processes and consists of three main geomorphological units. Most of the oblast, including the territory of the Sumy Forest District, lies within the Dnipro Lowland, characterized by relatively flat and slightly undulating terrain. The northernmost part of the oblast belongs to the Polissya Lowland, with its poorly drained plains and sandy river terraces. To the east and northeast lie the spurs of the Central Russian Upland, featuring more dissected terrain with elevations up to 240 meters. The territory of the Sumy Forest District ranges from 130 to 180 meters above sea level and is characterized by gently undulating relief dissected by river valleys, gullies, and ravines 20–30 meters deep [19-1].

The hydrographic network belongs to the Dnipro basin and is represented by its left tributaries. The forest district lies mainly within the Psel River basin, which flows through the eastern part of the oblast and has a well-developed valley 9–12 km wide, including a floodplain and three terraces above the floodplain. In addition to the Psel, the district is crossed by its tributaries – small rivers and streams with unstable water regimes. The rivers exhibit typical forest-steppe hydrological patterns, with pronounced spring floods, rain-fed flow in summer and autumn with flash floods after heavy rains, and stable low water levels in winter [20-1].

The soil cover of the territory is highly variable due to the transitional position between the Polissya and Forest-Steppe zones. On elevated terrain, gray forest soils dominate, with varying degrees of podsolization – from light gray to dark gray. Dark gray podzolized soils occupy the largest areas and are characterized by 3–4% humus content, a humus horizon thickness of 30–40 cm, and a medium loamy texture. In lower areas and on river terraces, sod-podzolic sandy and loamy soils prevail, with lower humus content (1.5–2.5%). In some locations, podzolized chernozems and meadow soils occur. The agrochemical assessment of soils in the oblast averages 51 points, one of the highest scores in Ukraine, indicating high natural fertility [15-1, 21-1].

Forestry and Taxation Characteristics of The Forest Fund

The forest fund of the Sumy Forest District is characterized by a predominance of coniferous and hardwood stands, typical for the Forest-Steppe zone of Ukraine. The total area of forest fund lands is 26,687.4 hectares, of which 24,434.8 hectares, or 91.6%, are directly covered with forest vegetation. The remaining area consists of lands not covered by forest, including clearings, glades, nurseries, firebreaks, mineralized strips, and other land categories with auxiliary functions for forestry operations. The forest cover index of the district exceeds the average for Sumy Oblast, which is 17.9%, since the district predominantly includes large continuous forest tracts [27-1].

Table 1. Distribution of the Sumy Forest District Fund by Dominant Tree Species

Species	Area, ha	Share, %	Stock, thousand m^3	Average Stock per ha, m^3
Scots pine (*Pinus sylvestris*)	9,680	39.6	2,904	300
Pedunculate oak (*Quercus robur*)	9,420	38.6	2,826	300
Silver birch (*Betula pendula*)	1,340	5.5	268	200
Common ash (*Fraxinus excelsior*)	1,245	5.1	374	300
Black alder (*Alnus glutinosa*)	1,075	4.4	215	200
Aspen (*Populus tremula*)	490	2.0	98	200
Small-leaved lime (*Tilia cordata*)	390	1.6	117	300
Other species	795	3.2	159	200
Total	24,435	100	6,961	285

The species composition of the forests reflects both the natural conditions of the region and the historical characteristics of stand formation. The main species is Scots pine (*Pinus sylvestris* L.), occupying 9,680 hectares, or 39.6% of the forested land. The second most common species is pedunculate oak (*Quercus robur* L.), covering 9,420 hectares, or 38.6%. Among other species, significant areas are occupied by silver birch (*Betula pendula*) – 1,340 hectares (5.5%), common ash (*Fraxinus excelsior*) – 1,245 hectares (5.1%), black alder (*Alnus glutinosa*) – 1,075 hectares (4.4%), aspen (*Populus tremula*) – 490 hectares (2.0%), and small-leaved lime (*Tilia cordata*) – 390 hectares (1.6%). Other species, including Norway spruce (*Picea abies*), sycamore maple (*Acer platanoides*), elm (*Ulmus*), poplar (*Populus*), and fruit trees, together occupy approximately 795 hectares, or 3.2% of the forested area [33-1].

Analyzing the data from Table 2 it can be noted that two main species—Scots pine and pedunculate oak—dominate, together accounting for over 78 percent of the forest fund. Coniferous stands are represented almost exclusively by Scots pine, as European spruce occupies only minor areas on waterlogged sites.

Among the broadleaf species, oak predominates, along with ash and small-leaved lime, together covering approximately 45 percent of the area. Soft-leaved species—birch, aspen, and black alder—occupy about 12 percent and are mostly found as admixtures in mixed stands or form pure stands on waterlogged and disturbed sites.

The age structure of the stands has certain characteristics shaped by historical events of the past century. The average age of all stands is 65 years, indicating the predominance of middle-aged and maturing forests. For Scots pine, the average age is 58 years, and for oak, 72 years, which is associated with different growth rates and the timing of maturity of these species. Young stands up to 20 years old cover about 3,950 hectares, or 16.2 percent of the area; middle-aged stands (21–60 years) occupy 9,774 hectares, or 40.0 percent; maturing stands (61–80 years) cover 6,353 hectares, or 26.0 percent; and mature and overmature stands occupy 4,358 hectares, or 17.8 percent.

Table 2. Distribution of Stands in the Sumy Forest District by Age Groups

Age Group	Area, ha	Share, %	Average Age, years
Young stands (1–20 years)	3,950	16.2	12
Middle-aged (21–60 years)	9,774	40.0	42
Maturing (61–80 years)	6,353	26.0	70
Mature and overmature (>80 years)	4,358	17.8	105
Total	24,435	100	65

This age structure developed as a result of intensive forest restoration during the post-war period of 1945–1960 and the large-scale establishment of new forests in 1960–1980. The share of mature and overmature stands is gradually increasing, creating conditions for higher volumes of final felling in the coming decades.

The productivity of the stands is high. The total timber stock amounts to 6,961 thousand cubic meters, corresponding to an average of 285 cubic meters per hectare. The annual increment of timber is approximately 102.6 thousand cubic meters, or 4.2 cubic meters per hectare, which exceeds the average indicators for the region.

Forestry and Cultivation Activities of The Enterprise

The technologies for establishing forest plantations in the Sumy Overforestry Unit are based on many years of practical experience and modern advances in forestry science. Site preparation for forest cultivation is differentiated depending on land category and forest-growing conditions. On fresh clear-cut areas, after final felling, partial soil preparation is carried out by creating furrows using the combined forest plow PKL-70. This approach preserves the natural soil structure, undergrowth, and existing regeneration of valuable species. The furrows are 50–70 centimeters wide, 20–25 centimeters deep, and spaced according to the planned planting scheme, typically 2.5–3.0 meters apart. Former agricultural lands designated for afforestation undergo complete plowing to a depth of 25–30 centimeters, followed by harrowing to level the surface and control weeds.

The choice of species for plantations is determined by the type of forest-growing conditions according to Pogrebnyak's edaphic grid and the intended purpose of the future forest. In fresh pine forests (A_2) and subpine forests (B_2), Scots pine (*Pinus sylvestris*) is the main species for forest restoration, planted in a 1.5×1.5 meter scheme (initial density 4,444 seedlings per hectare) or 2.0×0.7 meters (7,143 seedlings per hectare), depending on the quality of the planting material and available funding. In fresh oak forests (D_2) and fresh oak-birch forests (C_2), oak plantations are established with a 2.5×2.5 meter or 3.0×1.0 meter scheme (1,600–3,333 seedlings per hectare). Oak plantations often include companion species—common ash, Norway maple, and small-leaved linden—in 10–20% of the total planting density, which enhances the biological stability of the stands.

Seedling production is carried out at the main forest nursery covering 8.5 hectares, located in the Nizivske Forest District. The nursery includes a sowing section of 3.2 hectares for seedlings, a seedbed section of 2.8 hectares for saplings, and auxiliary plots. The annual production of standard planting material is approximately 800–900 thousand units, of which about 60% is Scots pine, 25% is common oak, and the remainder includes ash, linden, maple, and other species. Scots pine seedlings are grown using two technologies: the traditional open-root system, where seedlings are grown in the sowing section for 2–3 years to standard size (height at least 12 cm, root collar diameter at least 2 mm), and container technology.

Container cultivation has been implemented in the enterprise since 2018, using special "Planta" trays with 90 cm^3 cells. The substrate consists of 70% sphagnum peat, 20% sand, and 10% perlite with added slow-release mineral fertilizers. Cultivation occurs in greenhouses with controlled temperature and humidity, allowing standard planting material 15–20 cm tall to be produced in a single growing season. Survival rates for container-grown seedlings reach 92–95%, compared to 85–88% for open-root seedlings, though container seedlings are approximately 1.8 times more expensive.

Table 3. Afforestation Volumes in the Sumy Overforestry Unit, 2020–2024

Year	Artificial Regeneration, ha	Natural Regeneration, ha	Total, ha	Seedlings Planted, thousand pcs
2020	72	26	98	288
2021	75	29	104	300
2022	68	24	92	272
2023	77	28	105	308
2024	73	27	100	292
Average	73	27	100	292

Afforestation volumes in the Sumy Overforestry Unit have remained relatively stable in recent years. On average, 95–105 hectares of forest are restored annually, with 70–75 hectares through artificial planting of seedlings or sowing of seeds, and 20–30 hectares through natural regeneration under the canopy of parent stands or on clear-cuts with sufficient viable understory. Artificial regeneration is primarily carried out on areas affected by sanitary clear-cuts due to dieback from pests or diseases, as well as on final-felling clear-cuts in mature and overmature stands.

Analysis of the data in Table 2.3 shows that the volumes of forest regeneration have remained relatively stable, with minor fluctuations from year to year. The slight decrease in 2022 was due to objective circumstances caused by Russia's military aggression against Ukraine, which led to temporary reductions in funding and limited access to certain forest areas. The ratio between artificial and natural regeneration remains approximately 73 to 27 percent, which generally corresponds to the recommendations for the forest-steppe zone, although in the future it would be advisable to increase the share of natural regeneration as a more cost-effective and ecologically justified method.

Methodology of The Study

The objects of the study were Scots pine (*Pinus sylvestris* L.) plantations aged 5, 10, and 15 years, established in the Nyzivske Forestry of the Sumy Over-Forestry within fresh subor stands (forest site type B_2 according to the Pogrebnyak classification). These age categories were selected to track the dynamics of growth and development at critical stages: 5 years represents the results of survival and initial growth; 10 years corresponds to the period of active stem and crown formation after canopy closure; 15 years reflects plantations that have entered the pole stage. All studied plantations were established using container-grown seedlings from the forestry's nursery, with a uniform planting scheme of 2.0 × 0.7 m, corresponding to an initial density of 7,143 seedlings per hectare.

Sample plots were established following the requirements of DSTU 4633:2006 "Seeds of Trees and Shrubs. Methods for Determining Seed Quality" and the "Instructions for Designing, Technical Acceptance, Accounting, and Quality Assessment of Forest Plantation Objects," approved by the State Forestry Committee of Ukraine on 05.11.2010 No. 448. In each age category, three temporary rectangular plots of 0.25 ha (50 × 50 m) were laid out, providing sufficient representativeness for statistical analysis. Plots were randomly located within areas with homogeneous forest site conditions – fresh subor stands on dark gray podzolic loamy soils, flat relief, without waterlogging. Plot boundaries were determined using a Garmin GPSMAP 64 device with 3 m accuracy, and corners were marked with 80 cm wooden stakes labeled with the plot number.

On each plot, all trees were inventoried and assigned individual numbers, and a set of mensuration parameters was measured. Tree height was measured using a Blume-Leiss hypsometer with 0.1 m precision by sighting the terminal bud of the main shoot. Diameter at 1.3 m above ground (DBH) was measured using a caliper with 0.1 cm precision in two mutually perpendicular directions, then averaged. For 5-year-old plantations, most trees did not reach 1.3 m, so stem base diameter was measured with a Vernier caliper (ШЦ-I) to 0.1 mm accuracy. Each tree's condition category was visually determined according to sanitary rules in Ukrainian forests: I – healthy, II – weakened, III – severely weakened, IV – dying, V – fresh deadwood, VI – old deadwood.

Mensuration methodology included determining both individual tree parameters and average stand-level values. Plantation survival was calculated as the ratio of living trees (categories I-IV) at the time of measurement to the theoretical initial planting density of 7,143 seedlings/ha, expressed as a percentage. Mean height was calculated using the Lorrey method as the arithmetic mean of heights of trees closest to the stand's mean diameter. Mean diameter was computed as the quadratic mean of all tree diameters. Timber volume was determined according to standard mensuration tables for Scots pine juveniles developed by UkrNDILGA. To assess current growth intensity, annual height increment was measured on 10 model trees per age randomly selected from healthy trees (category I) as the length of the last year's shoot. Current diameter increment was measured using a Pressler increment borer by extracting two cores at 1.3 m in perpendicular directions.

Statistical analysis methods included calculation of basic statistical parameters for each mensuration variable: arithmetic mean, standard deviation, coefficient of variation, and standard error of the mean. Differences between age groups were tested using Student's t-test for independent samples at a significance level of $\alpha = 0.05$, commonly applied in forestry studies. Correlation analysis was used to determine the strength and nature of relationships between variables, e.g., between tree height and diameter, and between plantation age and survival. Data processing was performed using Microsoft Excel 2019 and specialized forestry mensuration software "Lisotaksator 3.0." Fieldwork was conducted from May to September 2024, with measurements taken twice per plot – at the start (May) and end (September) of the growing season – allowing assessment of seasonal growth dynamics.

Technology of Scots Pine Plantation Establishment in The Forestry

The technology of establishing Scots pine plantations in the Sumy Over-Forestry involves a set of sequential operations, starting with site preparation and ending with tending young stands until they are fully established. Soil preparation is differentiated depending on the land category and its previous use.

On fresh clear-cut areas after final felling, partial soil preparation is carried out by creating furrows with a combined forest plow PKL-70, mounted on a LHT-100 tractor. The plow forms furrows 60–70 cm wide and 20–25 cm deep, turning the topsoil along with the litter layer to one side. The distance between the centers of adjacent furrows is determined by the future planting scheme and usually ranges from 2.5 to 3.0 meters. The mineralized layer in the furrow provides favorable conditions for seedling survival, ensuring direct contact of the root system with mineral soil and reducing competition from herbaceous vegetation.

On former agricultural lands transferred for afforestation, soil preparation follows a different procedure. Initially, the stubble is harrowed using a BDT-3 disc harrow to a depth of 8–10 cm to stimulate weed seed germination. After 2–3 weeks, following mass emergence of weeds, a deep plowing is performed with a PLN-4-35 plow to a depth of 25–30 cm. In spring, before planting, the soil is cultivated and harrowed to level the surface and eliminate emerging weeds. This system significantly reduces weed infestation and creates optimal conditions for mechanized planting. On heavy loamy soils, additional subsoiling to 40–45 cm is performed to improve water permeability and aeration of the root-bearing layer.

Planting methods and spacing schemes are determined by the type of planting material, forest site conditions, and the intended purpose of the stand. Manual planting with a Kolesov spade is primarily used, which is the most common and reliable method for partially prepared soils. The Kolesov spade allows creating a furrow of the required depth, placing the seedling root system without bending, and firmly compacting the soil around the roots. For bare-root seedlings, planting depth is 15–18 cm; for container seedlings, it corresponds to the container height, usually 12–15 cm. The root collar is buried 1–2 cm below the soil surface to prevent drying of the upper root system.

The main planting scheme for Scots pine is 2.0 × 0.7 m, corresponding to an initial density of 7,143 seedlings per hectare. This density ensures formation of high-quality stands with straight, full-length stems through timely crown closure and natural branch self-pruning. On sites with better forest conditions, a sparser scheme of 2.5 × 0.8 m (5,000 seedlings per hectare) is applied to reduce planting material costs while maintaining stand quality. In fresh pine stands on poor sandy soils, a denser scheme of 1.5 × 0.7 m (9,524 seedlings per hectare) is used to compensate for expected losses and ensure sufficiently dense stands. Long-term experience supports these schemes, although precise optimization data for each case is limited.

The planting material used is critical for successful afforestation. In the Sumy Over-Forestry, Scots pine plantations are established using seedlings produced in the forestry's nursery, allowing quality control at all stages. Traditionally, two-year-old bare-root seedlings grown in the nursery were used, with the following standard characteristics: height 12–20 cm, root collar diameter ≥2.5 mm, root length 20–25 cm with well-developed lateral roots.

Since 2018, the forestry has introduced container-grown seedlings using "Planta 81F" containers (90 cm^3 volume). These seedlings are grown in a greenhouse during one growing season and reach 15–22 cm in height, with a root collar diameter of 2.8–3.5 mm. Compared to bare-root seedlings, container seedlings have significant advantages: higher survival rate, ability to plant at any time during the growing season, and better preservation of the root system during transport.

Thus, the technology of Scots pine plantation establishment in the Sumy Over-Forestry is characterized by a differentiated approach to soil preparation, predominance of manual planting with the Kolesov spade at a 2.0 × 0.7 m spacing, and gradual transition from traditional bare-root seedlings to container-grown seedlings, which increases the efficiency of forest cultivation operations.

Survival Rate of Scots Pine Plantations

Survival rate is one of the most important indicators of successful forest plantation establishment, as it determines the need for additional supplementary planting and, ultimately, the economic efficiency of afforestation.

The survival of Scots pine plantations was studied on plots established in 2020, 2021, 2022, and 2024, which allowed tracking the dynamics of this indicator over several years and identifying the factors that most significantly affect seedling survival.

Table 4. Survival of Scots Pine Plantations by Year of Establishment in the Nizivske Forestry of Sumy Forest District

Year of Establishment	Root System Type	Survey Area, ha	Planted, pcs/ha	Survived, pcs/ha	Survival Rate, %
2020	(DRS)	0.75	7143	6071	85.0
2020	(CGS)	0.75	7143	6643	93.0
2021	(DRS)	1.20	7143	6214	87.0
2021	(CGS)	1.20	7143	6714	94.0
2022	(DRS)	0.85	7143	5714	80.0
2022	(CGS)	0.85	7143	6500	91.0
2024	(DRS)	1.50	7143	6357	89.0
2024	(CGS)	1.50	7143	6786	95.0

Survival was recorded in the autumn of the planting year through a complete count of living seedlings on temporary monitoring plots of 0.25 hectares, established under typical conditions for each year of plantation establishment.

Analyzing the data from Table 3.1, it can be concluded that the survival rate of cultures created with container-grown seedlings consistently exceeds that of bare-root seedlings by 6–11 percent. The average survival rate over four years for container-grown seedlings is 93.3%, whereas for bare-root seedlings it is only 85.3%. The lowest survival rates were recorded for the 2022 plantings, which can be attributed to unfavorable weather conditions during the growing season – abnormally high temperatures in May–June and a deficit of precipitation. It is worth noting that even under such adverse conditions, the survival of container-grown seedlings remained relatively high.

The effect of root system type on seedling survival can be explained by several factors. Container-grown seedlings maintain an intact root system because their roots develop within the container and are not cut during extraction. This allows the plants to resume growth more quickly after planting and minimizes the stress adaptation period. In addition, the peat substrate surrounding the roots of container seedlings provides supplemental nutrients during the initial stage and maintains an optimal moisture level in the root zone. Bare-root seedlings, when dug up, lose a significant portion of their fine absorbing roots, which reduces their ability to take up water and minerals during the first weeks after planting.

The dependence of survival on site conditions is also quite clear. The highest survival rates are observed in fresh subor (B_2) stands on dark gray podzolized loamy soils, where survival for bare-root seedlings ranges from 87–90%, and for container-grown seedlings – 94–96%. In fresh pine stands on sod-podzolic sandy loam soils, survival is somewhat lower: 82–85% for bare-root seedlings and 90–92% for container-grown seedlings. This is due to the lower water-holding capacity of sandy soils and their tendency to dry out quickly during dry periods. Based on these comparisons, it can be concluded that the most critical factor for seedling survival is sufficient moisture during the first 2–3 weeks after planting, when the root system has not yet developed enough to effectively absorb water from deeper soil layers.

Table 5. Survival of Pine Plantations Depending on Forest-Growing Conditions

Forest-Growing Type	Soil Characteristics	Survival, Bare-Root Seedlings (%)	Survival, Container-Grown Seedlings (%)	Difference (%)
A_2 (fresh pine forest)	Sandy sod-podzolic	83	91	8
B_2 (fresh subor)	Dark gray podzolized loam	88	95	7
C_2 (fresh oak-pine mixed forest)	Gray forest light loam	86	93	7

The data in Table 5 show that container-grown seedlings have advantages across all types of forest-growing conditions, with the most pronounced effect observed in the poorest conditions of fresh pine forests, where the difference in survival reaches 8 percent. This assumption requires further confirmation on a larger number of plots, but the available data allow recommending the priority use of container-grown seedlings on poor sandy soils.

In addition to the type of forest-growing conditions, survival is influenced by the timing of planting—spring plantings (April) provide 3–5 percent higher survival compared to autumn plantings (October), due to more favorable moisture conditions and the absence of the risk of winter frost damage to weakened seedlings.

Thus, the survival rates of pine plantations in the Sumy Forest District are at a high level, especially when using container-grown seedlings, whose survival consistently exceeds 90 percent across all forest-growing conditions, indicating the effectiveness of the applied forest restoration technology.

The growth dynamics of Pinus sylvestris L. plantations of different ages were studied on nine sample plots established in 5-, 10-, and 15-year-old stands created in fresh subpine forests on dark gray podzolic loam soils. Three sample plots in each age category provided representative data on changes in key mensuration parameters with age and allowed assessment of the growth rates of Scots pine under the conditions of the Sumy Forest District. Measurements were conducted in August–September 2024 following the methodology described in Section 2, which ensured the possibility of accurate comparison of the obtained results.

Table 6. Height and Diameter Parameters of Scots Pine *(Pinus sylvestris* L.*)* Cultures of Different Ages

Age, years	Number of trees surveyed, pcs	Average height, m	Average diameter, cm	Survival rate, %	Health category
5	2680	1.8 ± 0.3	2.4 ± 0.4	93	I
10	2420	4.2 ± 0.6	5.8 ± 0.9	84	I
15	2150	7.5 ± 1.1	10.3 ± 1.6	75	I–II

Analyzing the data from Table 6, a clear pattern of increasing linear dimensions of the trees with age can be observed. Five-year-old cultures have an average height of 1.8 meters and an average diameter at 1.3 meters (or at the root collar for trees that have not reached this height) of 2.4 centimeters. By ten years of age, trees reach an average height of 4.2 meters, an increase of 2.3 times, while the diameter grows to 5.8 centimeters, an increase of 2.4 times. At fifteen years, the average height is 7.5 meters and the diameter is 10.3 centimeters.

It is noteworthy that the coefficient of variation in height and diameter increases with tree age: at 5 years, it ranges from 16–17%, while at 15 years it reaches 14–16%, indicating greater differentiation among trees due to competition for light, water, and mineral nutrients.

Annual growth shows uneven dynamics, associated with the biological characteristics of Scots pine growth. In the first 3–4 years after planting, growth is relatively slow – the average annual height increment is about 30–40 cm, and diameter growth is 0.4–0.5 cm. This period is characterized by intensive root system development and adaptation to site conditions. After crown closure, which occurs at 6–7 years of age, the phase of intensive height growth begins – the average annual increment increases to 50–60 cm, while diameter growth reaches 0.8–1.0 cm per year.

Based on this comparison, it can be concluded that the maximum growth rates in fresh subor conditions occur between 8–12 years of age, when trees have not yet experienced strong competition but have already developed a well-established root system.

The data in Table 7 clearly illustrate the pattern of increasing current annual increments with the age of the stands. While the average annual height growth during the first five years is 36 cm, it nearly doubles to 66 cm in the 11–15 year age period. Diameter growth shows a similar upward trend, rising from 0.48 cm/year in the first five years to 0.90 cm/year in the 11–15 year period. Although this observation requires further confirmation through long-term monitoring, the available data align well with the classical growth patterns of Scots pine stands in the forest-steppe zone.

Table 7. Presents the current annual increments of Scots pine cultures by age period

Age period, years	Average annual height increment, cm/year	Average annual diameter increment, cm/year
1–5	36	0.48
6–10	48	0.72
11–15	66	0.90

A comparative analysis of the sample plots revealed some variability in growth indicators even within the same type of forest-growing conditions. Among the three plots in the 15-year-old stands, the difference in average height ranged from 7.2 to 7.9 m, and in diameter – from 9.8 to 10.9 cm. This variability can be attributed to microclimatic differences between the plots, heterogeneity of the soil cover, and the quality of silvicultural operations performed during stand establishment. The best growth indicators were recorded on the plot located on the northern slope of a gentle hill, where trees were better supplied with moisture and protected from drying southern winds. The lowest growth was observed on a plot with a shallow clay subsoil (70–80 cm depth), which limited the development of the root system downward.

Thus, the growth dynamics of Scots pine stands in the Sumy Forestry Enterprise are characterized by a gradual increase in growth rates after the adaptation period, reaching maximum values at 10–15 years of age, indicating favorable conditions for Scots pine cultivation in the study region.

Condition and Productivity of Scots Pine Stands

The sanitary condition of the pine stands was assessed using the tree condition categories in accordance with the Sanitary Rules in the Forests of Ukraine. On each plot, all trees were classified into categories: I – healthy (no signs of weakening), II – weakened, III – strongly weakened, IV – dying, V – recently dead, VI – old dead. The inventory results showed that the overall sanitary condition of the studied stands is rated as good or satisfactory, depending on the age of the stands. In 5-year-old stands, the proportion of healthy trees (Category I) was 91 %, weakened (Category II) – 6 %, strongly weakened and dying (Categories III–IV) – 2 %, and no dead trees were recorded. This distribution indicates successful establishment and the absence of significant stress factors during the formation of young stands.

The stand volume of Scots pine plantations was calculated using volumetric tables for young pine stands developed by UkrNDILGA. For 10-year-old stands, the volume is 32 m³/ha, which corresponds to an average of 0.005 m^3 (5 dm^3) per tree. Fifteen-year-old stands have a volume of 122 m^3/ha, with an average of 0.023 m^3 per tree. The current annual volume increment, calculated as the difference in volumes divided by the number of years between measurements, is 3.2 m^3/ha/year for the 5–10-year period and increases to 8.1 m^3/ha/year for the 10–15-year period. These figures correspond to high-productivity stands and indicate the effectiveness of the applied silvicultural practices.

Thus, the sanitary condition of the Scots pine plantations in the Sumy Forestry Enterprise is assessed as good, tree survival meets regulatory requirements, and the indicators of site quality, stand density, and volume demonstrate high productivity and favorable growing conditions for Scots pine.

Based on the conducted research, it is recommended to further expand the use of planting material with a closed root system, which provides 6–11 % higher survival compared to traditional seedlings and allows for a broader range of optimal planting periods, including summer. It is also advisable to optimize the planting patterns depending on the forest-growing conditions: in fresh sub-boreal gray forest loamy soils, an initial density of 6,000–6,500 container-grown seedlings per hectare is sufficient, while in fresh pine stands on sandy soils, the traditional density should be maintained or slightly increased.

Regarding silvicultural techniques, it is recommended to improve soil preparation technology by using selective furrow creation instead of continuous plowing, and on former agricultural lands – pre-sowing of green manure crops. Critically important is the intensive care during the first 2–3 months after planting, including two soil treatments and weed control, with a subsequent reduction in care intensity to once per year during the second and third years, followed by standard forestry maintenance after crown closure at 6–7 years of age.

Conclusions

Analysis of the literature shows that *Pinus sylvestris* L. is characterized by high ecological plasticity, a wide natural range, and the ability to grow successfully on soils of varying fertility. In the conditions of the North-Eastern Forest-Steppe of Ukraine, Scots pine forms productive stands of site quality class I–II, but the effectiveness of forest regeneration largely depends on the correct choice of plantation technology and the quality of planting material.

The natural and climatic conditions of the Sumy Forestry Enterprise (moderately continental climate, mean annual temperature 6.6–6.8 °C, annual precipitation 550–675 mm, predominance of dark-gray podzolic loamy soils) are favorable for the cultivation of *Pinus sylvestris* L. The forest fund is dominated by pine (39.6%) and oak (38.6%) stands, with an average age of 65 years and a total volume of 6,961 thousand m^3.

It has been established that the survival rate of Scots pine plantations created with container-grown seedlings (closed root system) consistently exceeds that of seedlings with an open root system by 6–11% across all forest-growing conditions. The average survival of container seedlings is 93.3%, compared to 85.3% for open-rooted seedlings. The highest survival rates (94–96%) were observed in fresh sub-boreal stands on dark-gray podzolic loamy soils.

Growth dynamics studies revealed a consistent increase in tree dimensions with age: 5-year-old plantations have an average height of 1.8 m and diameter 2.4 cm, 10-year-old – 4.2 m and 5.8 cm, 15-year-old – 7.5 m and 10.3 cm. Current annual height increment increases from 36 cm/year in the 1–5-year period to 66 cm/year in the 11–15-year period, while diameter increment rises from 0.48 cm/year to 0.90 cm/year. Maximum growth intensity occurs at 8–12 years, after the development of a strong root system.

The sanitary condition of the studied plantations is assessed as good: in 5-year-old stands, 91% of trees are healthy, while in 15-year-old stands – 78%. Stand survival naturally decreases from 93% at age 5 to 75% at age 15 due to natural mortality under competitive conditions. Productivity is high: the volume of 15-year-old stands is 122 m^3/ha, with site quality class I–II and stand density 0.8.

The economic efficiency of using container seedlings has been confirmed: despite the higher cost of container seedlings (8.5 UAH vs. 5.3 UAH), additional expenses are offset by savings on supplementary planting (about 2,850 UAH/ha) due to higher survival rates and elimination of the need for repeat planting.

A set of recommendations has been developed for optimizing the cultivation technology of *Pinus sylvestris* L. under the conditions of the Sumy Forestry Enterprise, including: increasing the share of container-grown seedlings to 70–80% of total production, applying optimized planting patterns (2.2×0.7 m in fresh sub-boreal stands, 1.8×0.7 m in fresh pine stands), improving soil preparation methods, and refining the system of silvicultural treatments.

REFERENCES

1. Agrotechnology of Scots pine (*Pinus sylvestris* L.) seedling cultivation. URL: http://um.co.ua/5/5-1/5-1343.html (accessed: 05.10.2025).
2. Andreeva V. V., Voityuk V. P., Kychyliuk O. V., Hetmanchuk A. I., Tereshchuk A. M. Forestry and selection assessment of Scots pine stands in Cheremskyi Nature Reserve. Nature of Western Polissya and adjacent territories: collection of scientific papers / ed. by F. V. Zuzuk. Lutsk: East European National University named after Lesya Ukrainka, 2019. № 16. P. 176–184.
3. Biotechnology in forestry. URL: https://www.brc.a-star.edu.sg (accessed: 05.10.2025).
4. Boiko H. O., Puzrina N. V. Germination capacity and vigor of Scots pine (*Pinus sylvestris* L.) seeds of different colors. Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine. Series «Forestry and Ornamental Gardening». 2015. Issue 219. P. 113–117.
5. Boiko T. O., Boiko P. M., Pluhatar Yu. V. Ecological forestry: textbook. 2nd ed., revised and supplemented. Kherson: Oldi Plus, 2019. 268 p.
6. Boiko T. O., Melnyk M. A., Melnychenko L. D. Problems and prospects of forest management development in Kherson region in the context of forest and hunting management reform. Tavriyskyi Scientific Bulletin. 2017. № 97. P. 189–195.
7. Boiko T. Practical training of forestry specialists in southern Ukraine – a guarantee of sustainable regional development. 2021.
8. Vakulyuk P. H., Samoplavskyi V. I. Forest restoration and afforestation in Ukraine. Kharkiv: Prabor, 2016. 384 p.
9. Hordienko M. I., Huz M. M., Debryniuk Yu. M., Maurer V. M. Forest cultures: textbook. Lviv: Kamula, 2015. 608 p.
10. Davydenko K., Baturkin D. Ophiostomatoid fungi associated with bark beetles and colonizing Pinus sylvestris in Sumy region (Ukraine). Scientific Works of the Forest Academy of Sciences of Ukraine. 2020. № 21. P. 118–128. DOI: https://doi.org/10.15421/412037.
11. Danylenko O. M., Mostepanyuk A. A., Hupal V. V. Economic efficiency of growing seedlings with closed root systems and forest cultures using them in SE «Kharkiv LNSD». V. M. Vynogradov Scientific Readings: materials of the first open regional scientific-practical Internet conference dedicated to the 5th anniversary of the Department of Forestry and Landscape Architecture of Kherson State Agrarian University, Kherson, May 23–24, 2019. Kherson, 2019. P. 62–64.
12. Danylenko O. M., Yushchyk V. S., Rumyantsev M. H., Mostepanyuk A. A. Growth and condition of Scots pine cultures created with different planting materials in the South-Eastern Forest-Steppe of Ukraine. Scientific Bulletin of NLTU of Ukraine. 2021. Vol. 31, № 1. P. 26–29. DOI: https://doi.org/10.36930/40310104.
13. Debryniuk Yu. M., Yavorsky M. V., Myakush I. I. Selection inventory of permanent seed base objects of SE «Busk Forestry» and ways to restore genetic resources of main forest-forming species. Lviv: Manuscript, 2021. 152 p.
14. State Target Program «Forests of Ukraine» for 2010–2015: Resolution of the Cabinet of Ministers of Ukraine dated 16.09.2009 № 977 (as of 20 Mar. 2018). URL: https://zakon.rada.gov.ua (accessed: 05.10.2025).
15. State Enterprise «Forests of Ukraine». URL: https://e-forest.gov.ua (accessed: 05.10.2025).
16. Dyshko V. A., Dyshko S. M. Morphological characteristics of generative organs of Scots pine in natural and artificial stands in Ukraine. Scientific Bulletin of NLTU of Ukraine. 2015. Issue 25.2. P. 58–63.
17. DSTU 8558:2015. Seeds of trees and shrubs. Methods for determining sowing qualities (germination, viability, quality). Effective from 2017-01-01. Kyiv: UkrNDNC, 2017. 87 p.
18. Krynytsky H. T., Zaika V. K. Morphophysiological basis for genetic-selection assessment of tree growth intensity in forest stands. Forestry Science: status, problems, development prospects (UkrNDILGA – 90 years): materials of international scientific-practical conference, Kharkiv, June 23–24, 2021. Kharkiv: Planeta-Print, 2021. P. 258–260.
19. Lozinska T. P., Zadorozhnyi A. I., Masalskyi V. P. Study of new technologies and innovations in forestry. Agrobiology. 2024. № 1. P. 43–48. DOI: 10.33245/2310-9270-2024-1-43-48.
20. Lozinska T. P., Yatsenko V. M. Introduction as a tool to increase forest cover and improve species composition and biodiversity of forest plantations. Study and conservation of biodiversity of ecosystems of Ukraine: materials of the All-Ukrainian scientific-practical conference of students and young scientists, Bila Tserkva, April 20–23, 2021. Bila Tserkva: BNAU, 2021. P. 26–28.
21. Lyalin O. I. Methodical recommendations for performing practical works on forest seed production from the course «Forest cultures». Kharkiv: KhNUMG named after O. M. Beketov, 2018. 38 p.
22. Lyalin O. I., Tarnopilska O. M., Tkach L. I., Musienko S. I., Bondarenko V. V. Germination, survivability, and condition of Scots pine (Pinus sylvestris L.) seedlings grown in containers. Scientific Bulletin of NLTU of Ukraine. 2020. Vol. 30, № 2. P. 44–48. DOI: https://doi.org/10.36930/40300208.
23. Forest Code of Ukraine: Law of Ukraine dated 21.01.1994 № 3852-XII (as of 17 Feb. 2000). URL: https://ips.ligazakon.net/document/view/t385200?an=ul-1&ed=2000_02_17 (accessed: 05.10.2025).
24. Mazhula O. S., Fuchylo Ya. D., Shiyanova T. P., Skorokhodov M. Yu., Ryabchun V. K. Long-term preservation of Scots pine (Pinus sylvestris L.) seeds as a basis for creating fast-growing energy plantations on marginal lands in Ukraine. Scientific Works of the Institute of Bioenergy Crops and Sugar Beets. 2018. Issue 26. P. 84–90. DOI: https://doi.org/10.47414/np.26.2018.211208.
25. Manilych M., Konechna R. Scots pine (Pinus sylvestris L.): an analytical literature review. Modern Medicine, Pharmacy and Mental Health. 2023. № 2 (11). P. 96–108. DOI: https://doi.org/10.32689/2663-0672-2023-2-14.

FEATURES OF SUNFLOWER YIELD FORMATION

Trotsenko Volodymyr
Doctor (Agricultural Sciences), Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0001-8101-0849

Kolosok Inna
PhD (Agricultural Sciences), Associate Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0001-5970-0720

Zhatova Halyna
PhD (Agricultural Sciences), Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0002-8606-6750

Introduction. Yield and yield components are specific to sunflower varieties and hybrids, but they are influenced by various growing factors, both environmental and technological. Typically, the genetic potential of sunflower hybrids or varieties is reduced by the stress factors of cultivation [40].

Plant productivity depends on the ability to effectively use the variability of environmental factors at different stages of vegetation. When developing new agricultural technologies, due attention should be paid to the peculiarities of the phenological stages of plants [1, 3].

Seed yield is a quantitative trait and can be significantly influenced by the environment. It is a so-called "supertrait" and selection for any other trait is positively or negatively correlated with seed yield. Seed yield and individual yield components are specific to each sunflower hybrid, but are influenced by various growing factors (ecological and technological), including soil and climatic conditions. High-yielding varieties require an appropriate level of agricultural technology to produce yield [3, 19].

In sunflower, seed yield is determined by indirect traits, such as optimal plant density, growth period, plant height, and direct traits, such as head diameter, number of seeds per head/or per plant/unit area, seed weight, weight of 1000 seeds, number of seeds per head, etc. [7, 9, 12, 18, 24].

Sunflower productivity is determined by the complex interaction of the biological characteristics of the crop, environmental conditions and elements of growing technology. When assessing the efficiency of sowing, special attention is paid to the crop structure, which reflects the contribution of individual elements to the formation of the final yield.

The main elements of the sunflower yield structure are:

- plant density;
- head diameter;
- number of seeds per head;
- weight of 1000 seeds;
- oil content in the seeds

Plant density is a key regulator of productivity. For sunflower, the optimal density is usually 45–65 thousand plants/ha (depending on the moisture zone and hybrid). Excessive density reduces the diameter of the head and the weight of the seeds, while thinned crops form large baskets, but do not provide the maximum yield per area [35, 37].

The diameter of the basket is directly related to the potential number of seeds. It is formed in the early stages of organogenesis and largely depends on the provision of plants with moisture and nutrients, especially nitrogen and boron. Stress during this period leads to a decrease in the size of the head and, accordingly, the number of flowers. The seed number in the head is one of the most important components of the yield. This indicator is determined by the conditions during flowering and pollination. Lack of moisture, high temperatures or a deficiency of microelements (in particular boron) can cause incomplete and reduced seed setting [17, 31, 38].

One of the important characteristics that determine yield is 1000 seeds weight. It is characterized the level of filling and accumulation of reserve substances. This factor varies in plant varieties and hybrids within the same species and depends on growing conditions. The weight of 1000 seeds reflects the size of the seeds and their fullness. This parameter becomes important as a factor in achieving an accurate seeding rate, which, due to the density of sowing, affects the yield of plants per unit area. This indicator depends on the photosynthetic activity of plants during the filling period, the supply of potassium and moisture. Drought or premature aging of the leaf apparatus lead to the formation of thin seeds [15, 23, 31].

The weight of 1000 seeds is a variable parameter. It is influenced by genetic factors and the environment.

The variability of this trait size is characteristic both for different genotypes in the same area and for the same genotype in different areas. This parameter may be due to the matric origin of the seeds (the location of the rows of seeds in the head).

In the experiments of Radic et al. it was also recorded that the weight of 1000 seeds depended on the year of observation and genotype. Sterile lines had seeds of greater weight compared to seeds of restorer lines, which is explained by the active branching of the latter [31].

When studying different genotypes (CMS-based lines and restorer lines) under different growing conditions, it was found that the weight of 1000 seeds was higher in CMS-based lines than in restorer lines, which was expected, taking into account the branching of restorer lines. It was also found that the weight of 1000 sunflower seeds depended on the characteristics of the year of observation and the genotype under study.

Studies have shown that such traits as germination, 1000-seed weight, huskiness, protein content, and seed yield per hectare were most influenced by genotype. All of the factors studied separately caused significant differences in husk content and protein content in seeds

The fullness of the head reflects the efficiency of pollination and fertilization processes. It largely depends on the activity of pollinating insects, in particular bees, as well as on weather conditions during the flowering period.

The number of seeds per basket, seed weight and oil content as individual components of the crop structure and its quality are closely related to genetic factors and sensitive to environmental factors. In particular, late sowing dates are a powerful factor that reduces the oil content and yield of sunflower seeds. Late sowing dates are associated with higher temperatures during the growing season, which leads to excessive stem growth and a reduction in the time required for flowering [25, 27].

When determining the reactions of sunflower varieties to different sowing dates, it was found that they significantly affect the duration of ripening, plant height, head diameter, total number of seeds per head, seed setting efficiency, 1000-seed weight, seed yield, husking coefficient and oil content in sunflower varieties.

Early sowing dates provide the largest head diameter, total number of seeds per head, higher seed setting efficiency, 1000-seed weight and yield. While late sowing dates led to the highest oil content [26,27, 32].

The oil content in seeds is an important qualitative indicator of the yield. It is formed under the influence of the genetic characteristics of the hybrid, temperature conditions and the provision of plants with nutrients. Excess nitrogen can reduce oil content, while potassium and sulfur contribute to its increase [8, 11].

Among the environmental factors, water and temperature regimes are of decisive importance for sunflower. The critical periods are the budding phase - flowering and seed filling. It is at this time that the lack of moisture has the most negative impact on all elements of the crop structure.

The influence of higher temperatures and solar radiation negatively affects the seed filling phase. The seed filling phase varies greatly depending on the year, place and date of sowing due to fluctuations in temperature and solar radiation [4, 6,10,11].

Mineral nutrition is no less important. Sunflower is characterized by a high need for potassium, which regulates water balance and promotes seed filling. Phosphorus ensures the development of the root system, and boron plays a key role in the processes of flowering and fertilization. The need for sunflower fertilizers depends not only on the soil, but also on climatic conditions, the yield of a particular variety, agrotechnical and organizational factors [8,14,17].

Nutrient management is one of the main factors affecting sunflower yield, seed oil content and fatty acid ratios. Sunflower removes many nutrients from the soil as a crop. Compared to other crops, sunflower is a significant nitrogen and phosphorus uptaker, and has no equivalent in potassium uptake.

Even with proper cultivation techniques, high or optimal yield levels are often not achieved due to insufficient soil fertility. Balanced fertilization plays a crucial role in providing sunflower with the nutrients necessary for maximum growth and development. Inorganic fertilizer components such as N, P and K are essential nutrients for plant growth and yield formation [14, 17, 21].

The fertilizer requirements of sunflower varieties vary depending on environmental conditions, rainfall, irrigation regimes, etc. During the growing season, sunflowers use nutrients unevenly.

A large amount of nitrogen and phosphorus is consumed by plants before flowering, when leaves, stems and root systems are formed. After this, phosphorus use decreases sharply. Potassium is absorbed by sunflowers throughout the growing season, but especially intensively before the flowering phase [8].

Although sunflowers respond less well to mineral fertilizers than grain crops, sufficient amounts of nitrogen, phosphorus, and potassium fertilizers must be provided in production.

Nitrogen (N) is the most important nutrient for increasing the yield and quality of sunflower seeds. This element stimulates plant growth and development, affects yield and quality. Nitrogen enhances vegetative growth and the rate of photosynthesis, gives plants their green color, and is a component of chlorophyll [24].

Nitrogen deficiency causes modification of many morphological and physiological parameters: growth restriction, leaf number and leaf area have been reported. Higher doses of nitrogen improve the photosynthesis process, increase the leaf surface area.

Sunflower yield is the result of the formation and interaction of elements of the crop structure. Management of seeding density, nutrition, water regime and plant protection allows to optimize these elements and ensure maximum realization of the hybrid's potential. An integrated approach to regulating environmental factors is the basis for stable and high-yielding sunflower cultivation.

Sunflower yield is the product of 3 components:

a) number of head per hectare;

b) number of seeds per head;

c) average seed weight.

Since most varieties form one inflorescence/head per plant, component (a) is determined by the number of plant populations. The other two components are influenced by the first component, variety characteristics, abiotic (weather conditions), edaphic and biotic (pests, diseases) factors.

Certain morphological characteristics of the plant are varietal characteristics, but under the influence of environmental factors and growing technology they can change. In particular, nitrogen fertilizers increase the yield of sunflower hybrids, increase the diameter of the basket [21, 28]. Characteristics such as grain yield and oil content in sunflower are complex and are determined by genetic, ecological and genotypic interactions of the environment.

It is difficult to develop criteria for characterizing and assessing productivity under the strategic interaction of genotype with the environment. Sunflower seeds are characterized by almost 100 different traits. Only 20 of them have production significance, the functions of 10-15 are still being studied, and all the others are beyond the attention of scientists [1, 3].

In the process of selection work to obtain varieties and hybrids for the northern regions, such characteristics as seed yield per plant, weight of 1000 seeds, solar radiation intensity, stem diameter and basket diameter should be taken into account. Given the results of the experiment, it can be concluded that the northern latitudes have good potential for sunflower production.

A wide range of originators and the availability of seed material provide the opportunity to select the optimal list of hybrids for different conditions and growing technologies. Along with this, against the background of the tendency to increase the contrast between weather conditions in individual years, there is an increase in demand for unified genotypes with an increased level of adaptability to the complex of agroecological environmental conditions. The presence of several different vectors of sunflower crop development necessitates the improvement of genotype identification methods, approaches to the selection of the analyzing background and evaluation indicators.

Conditions, materials and research methods.

Soil conditions. The soil of the experimental site is typical of the northeastern Forest-Steppe of Ukraine, classified as a powerful heavy loamy medium humus chernozem on loess-like loam. According to the agrochemical analysis, the soil was characterized by the following indicators: the humus content in the arable layer was 3.6%, the reaction of the soil solution was close to neutral (pH 6.3), the content of easily hydrolyzed nitrogen was 8.3 mg, mobile phosphorus and exchangeable potassium were 12 mg and 7.2 mg per 100 soil, respectively. During the research period, the predecessor was spring barley. The main soil tillage was improved cold plowing in the second decade of October to a depth of 22–24 cm. Mineral fertilizers were applied in the spring for pre-sowing cultivation in the form of nitroammophos fertilizers ($N_{15}P_{15}K_{15}$) according to the experimental scheme.

Weather conditions. The dynamics of soil and air temperatures in the northeastern Forest-Steppe zone of Ukraine are provided by optimal conditions for sunflower vegetation from May to September. Vegetation at earlier times is limited by low spring soil temperatures. The shift of vegetation to the autumn months is blocked by a decrease in daily temperatures (less than +14 °C), starting from the second decade of September.

Under these conditions, the most favorable date for sowing is the third decade of April, while September is considered exclusively as a period of technological maturation. Therefore, the weather conditions of the period "May-August" have a decisive influence on the development of vegetative organs of plants, the flowering phase, the formation and filling of seeds, (table 1).

Table 1. Main indicators of weather conditions during the sunflower growing season (May-August).

Indicator	Years		
	2019	2020	2021
Sum of temperatures, C	2614	2447	2592
Precipitation, mm	120	219	230
Hydrothermal coefficient (GTC)	0,46	0,89	0,89

In general, the weather conditions of the 2019–2021 growing seasons contributed to the identification of genotypes capable of intensive growth in conditions of reduced temperatures and sufficient water supply in the juvenile phases of development, as well as the combination of these traits with the ability to accumulate photosynthesis products in arid conditions of the second half of the growing season.

The research material was nine sunflower hybrids selected based on the results of environmental tests, namely the onset of the technological maturation phase by September 20. The duration of the vegetation period of these hybrids declared by the originators ranged from 110 to 115 days, (Table 2).

Table 2. General characteristics of sunflower hybrids (open data from originator institutions)

Hybryd		Height of stem, cm	Diameter of inflorescens, cm	1000 seed weight, g	Yield potential, t/ha	Seed oil content, %
1	Phenomen	170–180	19–20	55-56	4,3	50–51
2	Nabir	150–160	18–20	50	4,0	50–55
3	Yason	175–185	22-24	62	4,3	49–50
4	Teo	185–195	17-19	58	4,2	48,0
5	Oscar	160–170	18-20	60-62	4,0	49–51
6	Agent	170–180	19–22	62	4,8	50
7	Zlanson	160–165	21–23	till 60	4,7	48,4
8	LG 53.77	155–165	16-18	70	5,0	49–50
9	Dobrodiy	175–185	20–22	52	5,0	48,3

Research methods. Experimental studies were conducted according to the scheme of a 3-factor field experiment on the experimental field of Sumy National Agrarian University, (Table 3). The plots were 2-row, 9 m long, with an area of 12.6 m^2. Repetition was 3 times.

The placement of plots by factor A was randomized, by factors B and C was systematic. Depending on the tasks, calculations were carried out according to the scheme of a one-, two- or three-factor experiment. In some cases, weather conditions were considered as a separate factor.

Table 3. Scheme of field research with the development of characteristics and the formation of productivity of dormouse hybrids (2019–2021)

Factor A – hybrid	Factor B – fertilizer rate	Factor C – final seeding density
• Phenomen • Nabir • Yason • Teo • Oscar • Agent • Zlanson • LG 53.77 • Dobrodiy	• Without fertilizers (control); • $N_{45}P_{45}K_{45}$; • $N_{90}P_{90}K_{90}$	• 45 thousand plants/ha; • 55 thousand plants/ha; • 65 thousand plants/ha

Results.

Development and structure of the leaf surface of sunflower hybrids. At the current stage of breeding, the model of development of the leaf apparatus of plants is increasingly considered as the main element of the adaptability of genotypes to specific growing conditions, geographical zoning zones, etc.

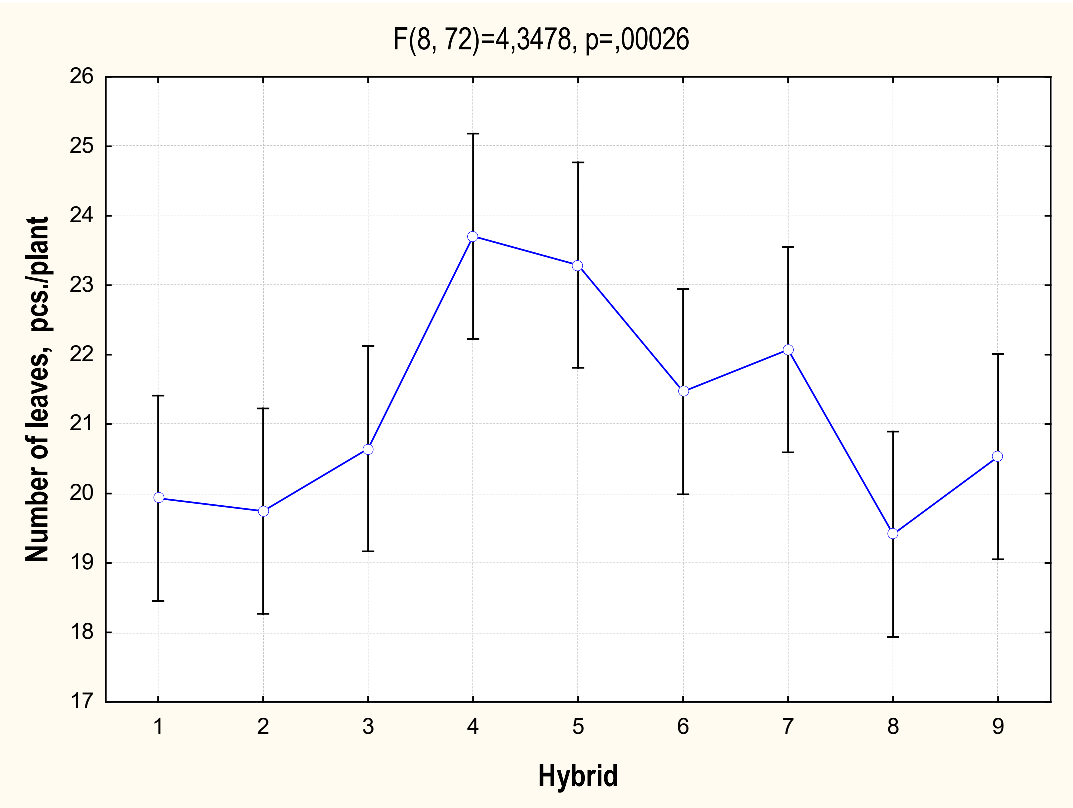
The basis of this approach is the primacy in plant ontogenesis of programs for the implementation of vegetative potential, while the object of breeding programs (the entire period of domestication of the crop) are the parameters of generative development, the programs of which are implemented in the second half of the plant vegetation [39].

Under these conditions, the potential of the hybrid, the range of its adaptability to environmental conditions is determined by the level of interaction between the development of the assimilation apparatus and generative organs. Thus, in each specific case, its own, original scheme of donor-acceptor relationships is formed, which regulate the formation of photosynthesis products, growth processes, life support and accumulation of reserve nutrients.

Number of leaves. The apical type of inflorescence formation in single-inflorescens forms of sunflower determines a high level of genetic control of the trait of leaf number. Since inflorescence formation in sunflower plants occurs in the juvenile phases of development, environmental conditions only partially determine the number of leaves that the plant forms during the growing season.

Currently, in breeding practice, it is accepted to estimate the potential duration of this period based on the calculation that the formation of one leaf occurs in 2.5–3.0 days. The average data on the number of leaves in each of the sunflower hybrids in the experimental plots are shown in Fig. 1.

The total level of variation of this trait varied from 18.5 to 26.7 pieces per plant. Such a significant range can be explained by the peculiarities of the formation and life span of individual leaves. Thus, in areas with the maximum level of thickening, even in the middle of the flowering phase (taking into account the main morphological parameters of plants), the dying off of the lower tier of leaves was observed. However, in some years, especially in thinned crops, the last pair of leaves (mostly underdeveloped) formed full-fledged leaf blades.



1 – Phenomenon; **2** – Nabir; **3** – Yason; **4** – Teo; **5** – Oscar; **6** – Agent; **7** – Zlatson; **8** – LG 53.77; **9** – Dobrodiy

Figure 1. Dynamics of the average number of leaves of sunflower hybrids, pieces/plant.

Analysis of the figure shows that the overall level of variation of this trait varied from 18.5 to 26.7 pieces per plant.

Such a significant range can be explained by the peculiarities of the formation and life span of individual leaves.

Thus, in areas with the maximum level of thickening, even in the middle of the flowering phase (taking into account the main morphological parameters of plants), the dying off of the lower tier of leaves was observed.

However, in some years, especially in thinned crops, the last pair of leaves (mostly underdeveloped) formed full-fledged leaf blades.

According to the average value of the indicator, it is advisable to distinguish three groups, namely:

- hybrids Phenomen, Nabir, LG 53.77, which formed less than 20 leaves (19.4–19.9);
- hybrids Yason, Agent, Zlatson, Dobrodiy formed 20.5–22 leaves;
- hybrids Teo and Oscar formed more than 23 leaves (23.3–23.7).

The presence of a statistically significant difference between the indicators of groups 1 and 3 indicates potential differences in the duration of the vegetation period, which in turn implies different algorithms for implementing generative functions.

Dynamics of indicators of the single leaf area. In the theoretical aspect, the presence of differences in the algorithms for the formation of the yield of sunflower hybrids is based on the primacy of the development of vegetative organs of plants and the realization of their generative potential on this basis.

Due to the gradual nature of growth processes, the parameters of generative development are less dependent on environmental factors.

At the same time, the primacy of the realization of the vegetative potential itself can block the development of generative parameters in stressful environmental conditions.

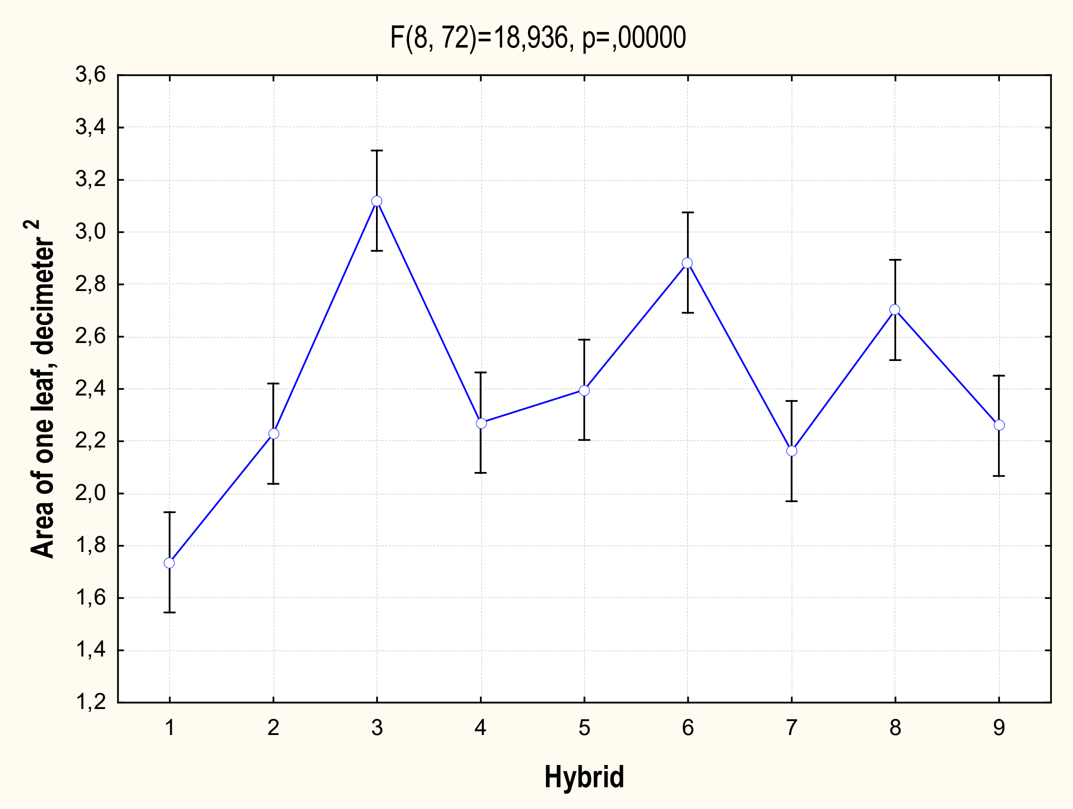
An additional factor limiting the size of the crop yield is the difference in the population and economic optima of the realization of the generative potential. In the first case, the determining factor is the indicator of the number of seeds formed per unit area.

In the case of the economic optimum, we are talking about the mass of fruits, which is determined by two indicators - the number and weight of 1000 seeds. The value of the latter (within one genotype, or a group of genotypes with similar parameters of plant development) is closely correlated with the duration of post-embryonic development of fruits.

The conditions for the postembryonic period of fruit development (seed filling phase) are determined by the level of provision of the formed embryo with water and photosynthesis products. The root system, size and structure of the plant's leaf apparatus play a decisive role in this.

The next stage in the study of the features of the formation and functioning of the leaf apparatus in early-ripening sunflower hybrids was the determination of the average leaf size and structure of the crop leaf layer. The area of an individual leaf directly affects the intensity of photosynthesis: the larger the leaf surface, the more solar energy is absorbed to form organic substances. Too large leaves can overlap each other, reducing the efficiency of light absorption, while a small surface area limits growth even with high activity of an individual leaf. Leaves should form an optimal area that will ensure maximum photosynthesis efficiency and productivity.

The graph of the average values and the range of variability of the average leaf blade area of sunflower hybrids is shown on the Fig. 2.



1 – Phenomenon; **2** – Nabir; **3** – Yason; **4** – Teo; **5** – Oscar; **6** – Agent; **7** – Zlatson; **8** – LG 53.77; **9** – Dobrodiy

Figure 2. Dynamics of the average leaf blade area of sunflower hybrids, dm².

Analysis of the values indicates a significant difference between the average leaf blade size indicators of the hybrids. In ascending order of the indicator, from 1.74 to 3.14 dm², the hybrids were ranked in the following sequence: Phenomenon, Zlatson, Nabir, Teo, Dobrodiy, Oscar, LG 53.77, Agent, Yason.

The range of variation of the average values provided the possibility of distinguishing three groups that statistically significantly differed in the values of the indicator, namely:

- with minimum values– hybrid Phenomenon;
- with transitional values– Nabir, Teo, Oscar, Zlatson, Dobrodiy;
- with maximum values– Yason, Agent, LG 53.77.

Generalized information on the dynamics of the leaf blade area indicator in terms of fertilizer and density factors is presented in Table 4.

Data analysis shows a gradual increase in the leaf blade area, on average by 8–9% with a multiple increase in the rate of mineral fertilizers. In terms of the density factor, a reverse reaction was observed. The difference between the leaf area in plots with a minimum density and 55 and 65 thousand/ha was 7.7 and 11.2%, respectively.

Table 4. Average values of the leaf blade area index of sunflower hybrids depending on the fertilizer rate and sowing density

Factor		**X**	**± to control for the factor**		**Average for factor**	
B – fertilizer rate, active ingredient. kg/ha	**C** – sowing density, thousands of units/ha		B	C	B	C
No fertilizers (control)	45 (к)	2,41			2,22	2,58
	55	2,17		-0,24		2,38
	65	2,08		-0,33		2,29
$N_{45}P_{45}K_{45}$	45 (к)	2,52	0,11		2,41	
	55	2,39	0,22	-0,13		
	65	2,31	0,23	-0,21		
$N_{90}P_{90}K_{90}$	45 (к)	2,81	0,4		2,62	
	55	2,56	0,39	-0,25		
	65	2,49	0,41	-0,32		

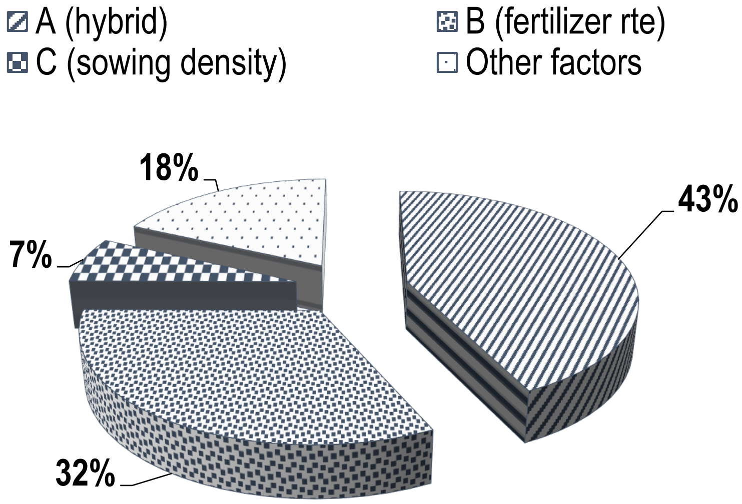


Figure 3. Structure of the influence of factors on the dynamics of the leaf area index of sunflower hybrids.

The results of the variance analysis show that the genotype had a decisive influence on the dynamics of the area of one leaf. The strength of the influence of this factor was 67.8%, the influence of the fertilizer and density factors was 11.8 and 6.4%, respectively.

Leaf surface area coefficient. One of the main indicators of potential sowing efficiency is the ability to intensively form and maintain sufficiently high leaf surface area indicators for a long time. The leaf surface area coefficient is a determinant of abiotic factors such as radiation interception, water exchange, and it is important variable for crop growth. This indicator measurement is essential for understanding the interactions between crop growth, cultivation ways, and environment conditions. Moreover it is important biological variable, because it represents the area exposed to solar radiation and measures the surface area responsible for gas exchange. According to literature data, the value of this coefficient in certain periods of development (beginning of the flowering phase) can reach 5.0–6.0. However, for the most part, the range of values of the indicator in the Forest-Steppe zone varies from 1.5 to 3.5. The higher the indicator value, the more solar energy the crop captures, but at very high values (above 6–7), the lower leaves are shaded, die, and productivity drops. The value of it significantly depends on the sowing density, sowing dates, varietal characteristics, and nutrition (in particular nitrogen).

In the study, on average, the coefficient value for the experiment was 2.81. Depending on the conditions of the years, the indicator changed from 2.62 in the hot and dry year of 2019 to 2.93 in the hot and moderately humid year of 2021 (2.62; 2.88; 2.93).

In general, the experiment clearly showed a trend towards an increase in leaf surface area in proportion to the increase in seeding density and the rate of mineral fertilizer application.

Thus, the application of fertilizers at the rate of $N_{45}P_{45}K_{45}$ was accompanied by an increase in the coefficient values from 2.3 to 2.77 or by 20.4%.

In areas with the maximum rate, the coefficient value was 3.34, which is 45.2% more compared to the control. A similar situation occurred in the density variants. A gradual increase in the sowing density from 45 to 55 and 65 thousand ha was accompanied by an increase in the indicator from 2.56 to 2.82 and 3.04, which was 10.1 and 18.7%.

Comparison of the growth rates of the coefficient values under the influence of the fertilizer and density factors indicates differences in the response in the variants with the maximum manifestation of the factor.

Thus, a multiple increase in the fertilizer rate from $N_{45}P_{45}K_{45}$ to $N_{90}P_{90}K_{90}$ was accompanied by a 25% increase in the coefficient, while the difference between the $N_{45}P_{45}K_{45}$ variant and the control was only 20.4%.

The opposite relationship was observed in the variants with an increase in density. As a result, such dynamics of the influence of factors provided a close to a linear type of response to changes in the coefficient in the experimental variants. The difference between the extreme values of the average indicators (1.99 and 3.61 m^2/m^2) was 70.2%.

Depending on the genotype nature, the average coefficient values varied from 1.87 in the Phenomenon hybrid to 3.57 in the Yason hybrid. However, the most clearly visible difference between the genotypes was in the reaction to the factors of changing the fertilizer rate and sowing density.

In the variants with the maximum values of the factors ($N_{90}P_{90}K_{90}$ and 60.0 thousand/ha), the difference between the control variant was 100 and more percent for the Yason, LG 53.77 and Agent hybrids; more than 60% for the Oscar and Zlatson hybrids. The minimum reaction to the influence of factors was noted in the hybrids of Dobrodiy (+44.2%), Teo (+43.1%), Nabir (+42.3%), and Phenomen (+32.1%).

As expected, the largest difference between the indicators of leaf surface area, namely 3.23 times, was noted for Phenomenon hybrid with a density of 45 thousand/ha without fertilizers and for Yason hybrid with a density of 65 thousand/ha and the fertilizer rate of $N_{90}P_{90}K_{90}$, - 1.62 and 5.24 m^2/m^2 respectively.

Generalization of data on the dynamics of the leaf apparatus of sunflower plants under the influence of technological factors allowed us to make the following findings.

The change in the development indicators of the leaf apparatus of plants was determined by the indicators of the leaves number, their area and tier distribution.

The determining factor in the dynamics of the area indicator of single leaf was the genotype. The strength of the influence of this factor was 67.8%.

The influence of fertilizer and density factors was 11.8 and 6.4%, respectively. The group with high indicators of the area of the leaf blade (> 2.8 dm^2) included the following hybrids: Jason; Agent and LG 53.77. The minimum indicators of 1.7 dm^2 were the Phenomenon hybrid.

For the group of medium-early hybrids, the average coefficient of the leaf area of crop was 2.81 m^2/m^2. In terms of the fertilizer factor, the coefficient value changed from 2.3 in the control to 2.77 (+20.4) and 3.34 m^2/m^2 (+45.2%). A similar situation occurred in the density factor variants. A gradual increase in the density of the crop from 45 to 55 and 65 thousand ha was accompanied by an increase in the indicator from 2.56 to 2.82 and 3.04, which amounted to 10.1 and 18.7%.

In terms of hybrids, the average values of the leaf area coefficient of sowing varied from 1.87 in Phenomenon hybrid to 3.57 in Jason hybrid. A statistically significant difference was noted in the reaction of hybrids to changes in fertilizer rates and sowing density.

In the variants with the maximum values of factors ($N_{90}P_{90}K_{90}$ and 60.0 thousand hectares), the difference between the control variant was 100 and more percent for the Yason, LG 53.77 and Agent hybrids; more than 60% for the Oscar and Zlatson hybrids. The minimum reaction to the influence of factors was noted in the hybrids of Dobrodiy (+44.2%), Teo (+43.1%), Nabir (+42.3%) and Phenomen (+32.1%).

For research period, the average index value of leaf surface area was 62.1%. In terms of hybrids, the highest share of shaded layers (more than 65%) was in the hybrids of Agent, Yason, Oscar. The lowest share was 46.1% in the hybrid of Phenomenon.

Table 5. Leaf area coefficient of sunflower hybrids depending on fertilizer rate and seeding density, % (2019–2021).

Factor											Average for factor		
B – fertilizer rate,. kg /ha	**C** – seeding density, thousand/ha	**A** – hybryds									X	**B**	**C**
		Phenomenon	Nabir	Yason	Teo	Oscar	Agent	Zlatson	LG 53.77	Dobrodiy			
No fertilizers	45	1,62	2,01	2,34	2,32	2,25	2,35	2,08	2,08	1,99	2,12	2,30	2,56
	55	1,70	2,13	2,37	2,69	2,58	2,44	2,15	2,22	2,34	2,29		2,82
	65	1,67	2,32	2,27	3,01	3,00	2,91	2,62	2,41	2,35	2,51		3,04
$N_{45}P_{45}K_{45}$	45	1,83	2,26	3,27	2,62	2,75	3,04	2,25	2,29	2,26	2,51	2,77	
	55	1,90	2,43	3,38	3,05	3,13	3,36	2,33	2,79	2,86	2,80		
	65	1,88	2,60	3,77	3,02	3,14	3,54	2,79	3,22	3,06	3,00		
$N_{90}P_{90}K_{90}$	45	1,98	2,39	4,63	3,05	3,23	4,08	2,75	3,11	2,36	3,06	3,34	
	55	2,14	2,55	4,85	3,31	3,59	4,26	3,07	3,72	2,71	3,36		
	65	2,14	2,86	5,24	3,32	3,79	4,64	3,46	4,17	2,87	3,61		
Average for factor **A**		1,87	2,39	3,57	2,93	3,05	3,40	2,61	2,89	2,53	2,81		

The difference between the values of the coefficient and the reaction of this indicator to changes in individual factors are more clearly illustrated by the results of the 2-factor analysis of variance (Fig. 4).

In this case, the choice of the tool of the 2-factor experiment, where the density factor was considered as separate repetitions, was determined by the scheme for calculating the leaf area coefficient of crop.

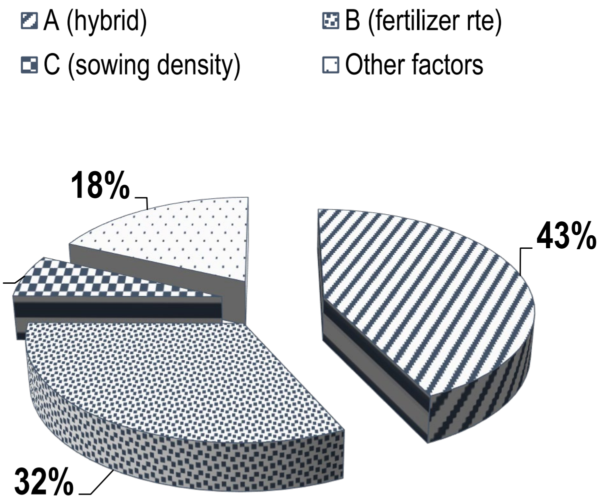


Figure 4. Structure of the factors influence on the indicator dynamics of leaf surface area of sunflower hybrids.

Dynamics of yield of sunflower hybrids depending on the rate of fertilizers and sowing density. The main indicator of the adaptability of the genotype to the growing conditions is the level of implementation of its generative functions.

In the evolutionary aspect, it was this characteristic that ensured the spread and consolidation in the genotype of individual mutations that determined deviations in the rates of passage of individual phases of development, the size and efficiency of the photosynthetic apparatus of plants, the division of photosynthesis products between individual parts of plants.

Traditionally, sunflower is considered as one that responds little to seasonal application of mineral fertilizers. This view is based on the peculiarities of the development of the plant root system, namely the dominance of the main root with the concentration of its active part at a depth of more than one meter. Under these conditions, the increase from the use of fertilizers is determined by the average rate of fertilizers applied in crop rotation.

At the same time (especially in recent years) sunflower is increasingly considered as an intensive type of crop, which provides a stable increase in yield precisely in technologies with the introduction of higher than average (in crop rotation) rates of mineral fertilizers.

Analysis of available literary sources shows that the reasons for the change in approaches to the crop are the selection and technological modernization of the crop. First of all, an increase in the number of hybrids capable of effective absorption of mineral elements from the upper (arable) layer of soil, improving the quality (primarily the level of solubility) of fertilizers, the use of complex mineral fertilizers, etc.

Data on yield by three-factor experiment variants is presented in Table 6. The average yield in the experiment over the research period was 2.91 t/ha, changing from 3.22 in the favorable year of 2019, to 2.92 and 2.59 in 2020 and 2021, respectively.

The results analysis of variance indicate the dominant role of factor A (hybrid) in the favorable year 2019 (the share of the factor's influence was 60.2%) with a gradual decrease in the influence in 2020 and especially in 2021. The opposite dynamics was observed for the mineral fertilizer factor, the influence of which was 16.5; 17.5 and 52.2% in 2019, 2020 and 2021, respectively.

A significant difference in the share of "other" factors, namely 23.0% in 2019 and only 12.5% in 2021, shows that the formation of high yields involves the presence of additional weather factors specific to 2019.

The minimal influence of the density factor on changes in yield indicators indicates its secondary role in the processes of forming crop yields.

The highest average yield in the experiment of 3.99 t/ha was noted on the LG 53.77 hybrid variant with a density of 55 thousand/ha and a fertilizer rate of $N_{90}P_{90}K_{90}$. Under the same conditions, a similar yield indicator (3.96 t/ha) was provided by the Agent hybrid.

In terms of individual years, the maximum yield indicator of 4.44 t/ha was noted in 2019 for the Agent hybrid on plots with a density of 45 thousand/ha and fertilizer application at the rate of $N_{90}P_{90}K_{90}$.

In general, on the base of increasing average yield, the hybrids were arranged in the following order: Phenomenon (2.3 t/ha), Yason (2.37 t/ha), Dobrodiy (2.98 t/ha), Nabir (2.58 t/ha), Teo (2.9 t/ha), Oscar (3.02 t/ha), Zlatson (3.12 t/ha), LG 53.77 (3.4 t/ha), Agent (3.49 t/ha).

Depending on the characteristics of the growing season, changes in the rating of hybrids primarily concerned the rating of the Dobrodiy, which, more than other hybrids, reduced yield in less favorable years. The reverse dynamics, namely, an improvement in the rating in less favorable years for vegetation, was observed for the Nabir, Yason, and Zlatson hybrids.

In the technological aspect of sunflower cultivation, it is important to determine the reaction of hybrids to the application of medium and high doses of mineral fertilizers. The results of the experiment show that a stepwise increase in the rate of fertilizer application to the level of $N_{45}P_{45}K_{45}$ and $N_{90}P_{90}K_{90}$ was accompanied by an increase in yield from 2.56 to 2.93 and 3.22 t/ha or by 0.37 and 0.66 t/ha compared to the initial value (without fertilizers).

Under the conditions of using the average rate of fertilizers, the highest level of yield increase of 0.5 t/ha was noted in the Agent hybrid, the minimum increase, namely 0.3 t/ha, was provided by the Phenomenon, Nabir, and Jason hybrids. The most numerous was the proportion of hybrids in which the level of increase was 0.4 t/ha - Teo, Oscar, Zlatson, Dobrodiy and LG 53.77.

Table 6. Average yield of sunflower hybrids depending on fertilizer rate and sowing density, t/ha

Factor											for the option	Average for factor	
B – fertilizer rate,.kg /ha	**C** – seeding density, thousand/ha	**A** – hybryds										**B**	**C**
		Phenomenon	Nabir	Yason	Teo	Oscar	Agent	Zlatson	LG 53.77	Dobrodiy			
No fertilizers	45	1,89	2,16	1,99	2,45	2,62	3,18	2,82	3,20	2,90	2,58	2,56	2,90
	55	1,95	2,36	2,14	2,78	2,81	3,06	2,62	2,96	2,53	2,58		2,94
	65	2,36	2,34	2,19	2,39	2,49	2,88	2,81	2,74	2,38	2,51		2,88
$N_{45}P_{45}K_{45}$	45	2,09	2,40	2,22	2,75	2,94	3,58	3,18	3,62	3,28	2,90	2,92	
	55	2,27	2,75	2,49	3,26	3,30	3,54	3,09	3,48	2,97	3,02		
	65	2,68	2,66	2,49	2,72	2,86	3,24	3,17	3,10	2,69	2,84		
$N_{90}P_{90}K_{90}$	45	2,60	2,88	2,65	3,20	3,33	4,05	3,46	3,73	3,25	3,24	3,26	
	55	2,35	2,68	2,47	3,04	3,26	4,19	3,52	3,99	3,60	3,23		
	65	2,49	3,00	2,72	3,55	3,58	4,01	3,37	3,78	3,21	3,30		
Average for factor **A**		2,30	2,58	2,37	2,90	3,02	3,52	3,12	3,40	2,98	2,91		

A slightly different dependence was observed in the variants with a high rate of fertilizer application. Under the conditions of a proportional increase in the amount of fertilizer applied, only four hybrids (Teo, Oscar, Dobrodiy and LG 53.77) provided a yield increase close to the previous variant.

For the hybrids Nabir, Hason, Agent and Zlatson, the yield increase was only to 0.21–0.25 t/ha. The minimum effect of an increase in the amount of fertilizer applied was on the Phenomen hybrid, for which the yield increase was only 0.13 t/ha.

The analysis of variance conducted on individual factors indicates the presence of a statistically significant difference between the yield indicators for factor A and indicates the isolation of two groups that differ significantly in the level of realization of their biological potential.

The group with the minimum yield indicators (at the level of 2.3–2.37 t/ha), formed by the hybrids Phenomen and Yason, and the group consisting of the hybrids Agent and LG 53.77. The yield indicators of these groups differed statistically significantly regardless of the years of research and experimental variants.

Despite the significant dispersion of the yield index of different sunflower hybrids, on average they demonstrated a statistically significant increase in the yield index when using medium and high rates of mineral fertilizers.

The influence of the density factor was less certain. Analysis of the experimental results indicates the absence of a clear response of the yield index to changes in the final density values, which indicates the inexpediency of its isolation as an independent (universal) factor of technology. Thus, this parameter should be considered as a derivative determined by the nature of the variety and the rate of fertilizers.

Yield structure. Plant productivity. An important feature of the hybrid's compliance with the complex of soil and agrotechnical conditions is the ability of plants to form high and stable indicators of individual seed productivity.

Modern sunflower crop, although it uses branched multi-head forms (which are the dominant type in natural populations) in the breeding process, is oriented towards the use of single-head forms with apical inflorescence formation.

Therefore, the orientation of natural selection and the modern breeding process to increase individual seed productivity have a number of differences, primarily related to the ability of plants to compete for environmental resources.

In natural populations, the process of vegetative branching and the formation of additional inflorescences is inter-connected, which provides the possibility of self-regulation of the generative load within a single plant and population.

Such a mechanism ensures the effective realization of the genetic potential of plants with simultaneous adjustment of their development (investment in reproduction) in accordance with the actual state of the environment.

Under the conditions of using single-head forms, the mechanism of self-regulation of the generative potential of plants, present in the basic (branched form), is less effective.

Under these conditions, the determining factor in the realization of the generative potential is the provision of parameters that meet the basic requirements of the genotype, especially in matters of levels of intraspecific competition. The dynamics of the productivity index of sunflower hybrids plants depending on the fertilizer rate and density are given in Table 7.

Over the years of research, the average productivity was 54.14 g. The range of variability of the average value was about 25%, varying from 59.87 g in the favorable year of 2019 to 54.49 and 48.06 g in 2020 and 2021, respectively.

Depending on the fertilizer rate, the indicator varied from 47.59 g in areas without fertilizer use to 54.32 and 60.52 g for the use of medium and high rates. In percentage terms, this was plus 14.4 and plus 11.5%.

More significant was the response of the indicator to changes in seeding density. On average, over 3 years, this indicator changed from 64.53 g in areas with a density of 45 thousand/ha to 44.38 g in areas with a density of 65 thousand/ha.

Table 7. Productivity of sunflower hybrid plants depending on fertilizer rates and sowing density, t/ha (2019–2021)

Factor											for the option	Average for factor	
B – fertilizer rate,.kg /ha	**C** – seeding density, thousand/ha	**A** – hybryds										B	C
		Phenomenon	Nabir	Phenomenon	Nabir	Phenomenon	Nabir	Phenomenon	Nabir	Phenomenon			
No fertilizers	45	41,85	48,08	44,30	54,37	58,30	70,59	62,67	71,04	64,37	57,28	47,59	64,53
	55	35,51	42,97	38,85	50,55	51,09	55,64	47,70	53,76	45,94	46,89		53,51
	65	36,36	36,05	33,69	36,82	38,25	44,26	43,18	42,10	36,56	38,59		44,38
$N_{45}P_{45}K_{45}$	45	46,52	53,26	49,26	61,04	65,41	79,48	70,67	80,45	72,96	64,34	54,32	
	55	41,27	50,00	45,21	59,27	60,00	64,30	56,18	63,28	54,06	54,84		
	65	41,28	40,97	38,36	41,79	43,95	49,85	48,72	47,64	41,34	43,77		
$N_{90}P_{90}K_{90}$	45	57,78	63,93	58,82	71,18	73,93	90,07	76,96	82,81	72,30	71,98	60,52	
	55	42,67	48,67	44,97	55,27	59,33	76,18	64,06	72,54	65,45	58,79		
	65	38,31	46,21	41,80	54,67	55,13	61,69	51,79	58,10	49,39	50,79		
Average for factor A		42,39	47,79	43,92	53,88	56,15	65,79	57,99	63,52	55,82	54,14		

Thus, the step-by-step decrease in the plant productivity indicator with an increase in seeding density was about 17% for every 10 thousand/ha. A comparison of the average values and levels of dispersion of the plant productivity indicator of individual hybrids indicates the presence of two clearly separated groups, namely, groups with minimum values at the level of 35–55 g/plant (Phenomenon, Nabir, Jason) and groups with a range of average values at the level of 60–73 g/plant (Agent, LG 53.77.). The transitional group was formed by the hybrids Teo, Oscar, Zlatson and Dobrodiy.

The difference between the average values of the indicator in the context of options B (fertilizer rate) and C (sowing density) was also statistically significant. An important addition to the characterization of the processes of crop yield formation is the analysis of the dynamics of the productivity indicator in years with different weather conditions.

Weight of 1000 seeds. In evolutionary terms, the formation of a massive inflorescence in the *Asteraceae* family ensured a deeper differentiation of seeds within one plant (due to the effect of matric heterogeneity), primarily in size and nutrient supply.

An important stage in the formation of sunflower culture was the isolation of populations of single-head forms. Single-head plant is a recessive trait with two alleles, which determines the dominance of multi-head branched forms. It was the isolation of the single-head form that gave impetus to effective selection for seed weight during the period of sunflower formation as a "garden crop".

The transition to the "field crop" of sunflower, which took place in the second half of the 19-th century, suspended selection on this basis. Due to the dominance of the "oil" ecotype and selection to reduce the huskiness of the seeds, genotypes with 1000-seed weight indicators at the level of 45–65 g gained priority. This value of the indicator was determined by "sufficiency" to ensure germination processes and technological processes of sowing. At the same time, this process is based on a close correlation between the mass of the kernel and the mass of the pericarp.

The trend towards an increase in the average weight of 1000 seeds in modern sunflower crops began to manifest itself only in the last twenty years due to the intensification of the confectionery direction of selection. This became an impetus for the creation of high-yielding genotypes with an increased contribution to the increase in yield due to an increase in the weight of 1000 seeds.

A derivative of this process was the differentiation of the varietal assortment of the crop by the predominant type of formation of plant productivity and crop yield. Currently, the highest level of differentiation is observed for groups of hybrids (and technologies) of traditional, oilseed and confectionery use of the crop. Table 8 presents data on the dynamics of the weight of 1000 seeds depending on the hybrid, mineral fertilizer rates and sowing density.

Table 8. Weight of 1000 seeds of sunflower hybrids depending on the fertilizer rate and sowing density, t/ha

Factor											for the option	Average for factor	
B – fertilizer rate, kg /ha	**C** – seeding density, thousand/ha	B - hybryds										**B**	**C**
		Phenomenon	Nabir	Yason	Teo	Oscar	Agent	Zlatson	LG 53.77	Dobrodiy			
No fertilizers	45	70,02	61,10	60,40	55,32	58,75	55,84	61,29	55,65	68,09	60,72		67,01
	55	67,63	61,07	59,74	51,68	57,18	53,27	57,12	50,34	63,30	57,93	57,58	65,24
	65	63,86	54,50	55,70	49,73	49,58	50,00	54,25	48,49	60,85	54,11		61,81
$N_{45}P_{45}K_{45}$	45	77,57	68,72	66,84	61,97	65,50	64,22	68,75	62,17	76,20	67,99		
	55	76,16	68,35	66,20	59,98	64,99	60,71	65,92	57,88	71,77	65,77	64,64	
	65	71,30	60,83	62,07	55,53	55,86	55,03	59,69	53,70	67,30	60,15		
$N_{90}P_{90}K_{90}$	45	83,77	74,15	74,51	66,67	70,27	67,31	71,86	64,99	77,31	72,31		
	55	85,67	73,58	74,57	67,12	71,44	66,11	71,06	62,95	75,59	72,01	71,83	
	65	84,13	73,84	73,35	65,95	69,65	65,49	71,30	62,29	74,61	71,18		
Average for factor **A**		75,57	66,24	65,93	59,33	62,58	59,78	64,58	57,61	70,56	64,69		

The average indicator was 64.7 g, changing from 66.5 g in the favorable year of 2019 to 63.9 and 63.6 in the less favorable for the formation of plant productivity years of 2020 and 2019. In terms of factor A, the highest indicators were observed in the hybrids: Phenomenon - 75.57 g and Dobrodiy - 70, 56 g. The minimum indicators of 57.61 and 59.33 g were characterized by hybrids LG 53.77. and Teo.

In terms of factors B and C, two opposite effects were observed, namely, an increase in the indicator in proportion to the increase in the rate of mineral fertilizers and a decrease in seed size with an increase in the sowing density indicators. The average value of 1000 seed weight in areas without fertilizer application was 57.58 g. An increase in the indicator to 64.4 g (+ 6.8 g) was noted in the variant with the application of $N_{45}P_{45}K_{45}$ and to 71.8 g (+7.4 g) in the variant with the maximum rate of fertilizers ($N_{90}P_{90}K_{90}$). Thus, the stepwise increase with a multiple increase in the rate of mineral fertilizers was +11.8 and +11.5%.

At the minimum (under experimental conditions) density of 45 thousand/ha, the value of the indicator was 67.0 g. A stepwise increase in density by 10 thousand/ha was accompanied by a decrease in values to 65.2 (-1.8 g) and 61.8 g (- 3.4 g). In percentage terms, this was minus 1.8 and minus 3.4% on plots with a density of 55 and 65 thousand/ha, respectively. The results of the analysis of variance, carried out in terms of individual factors, indicate the presence of a statistically significant difference between the options

A general analysis of the materials in the section shows that the dominant role in changing yield indicators under favorable conditions (2019) was played by the hybrid factor (the share of the factor's influence was 60.2%). In less favorable conditions (2020 and 2021), the influence of the hybrid factor decreased.

The opposite dynamics was observed for the mineral fertilizer factor, the influence of which was 16.5; 17.5 and 52.2% in 2019, 2020 and 2021, respectively. A significant difference in the share of "other" factors, namely 23.0% in favorable 2019 and less than 15% in 2020–2021, indicates that the formation of high yields requires additional (specific to 2019) weather conditions.

It was found that the use of medium and high rates of fertilizer provided an increase in the average yield from 2.56 to 2.93 and 3.22 t/ha, or by 0.37 and 0.66 t/ha, respectively.

When using medium rates of fertilizer, the highest level of increase (+ 0.5 t/ha) was provided by the Agent hybrid. In variants with high rates of fertilizer, the best indicators of yield increase were provided by the following hybrids: Teo, Oscar, Dobrodiy and LG 53.77.

In terms of the density factor, yield fluctuations were less significant and did not have a systemic nature. The absence of a statistically significant difference in the response levels of the yield indicator to changes in density indicates the inexpediency of isolating the latter as an independent factor of technology. Sowing density should be considered as a feature characterizing the nature of the variety or environmental conditions (fertilizer rate).

The use of medium and high fertilizer rates ensured an increase in the average plant productivity from 47.59 to 54.32 and 60.52 g/plant, or by 14.4 and 25.9%. The stepwise decrease in the productivity indicator (due to an increase in sowing density) was -17% for every 10 thousand plants/ha. The highest average productivity was observed for the hybrids 0f Agent 65.79 g and LG 53.77 63.52 g/plant

Changes in productivity indicators were determined by the dynamics of the parameters of the weight of 1000 seeds (and the number of seeds in the head). The highest values of the indicator were observed in the hybrids Phenomenon - 75.57 and Dobrodiy 79.56 g. In terms of the number of seeds, the ranking was led by the hybrids LG 53.77, Agent and Zlatson with indicators of 1118.5; 1089.3 and 901.6 pcs./plant.

The application of the average rate of fertilizers provided an increase in the indicator from 57.58 to 64.4 and 71.8 g, or by 11.8 and 23.3 %. The increase in plant density was accompanied by a decrease in the indicator from 67.0 (45 thousand/ha) to 65.2 and 61.8 g.

Conclusion. The experiment and the analysis of the collected digital material allowed us to draw the following general conclusions regarding the peculiarities of the formation of the yield of sunflower hybrids in the conditions of the northeastern Forest-Steppe of Ukraine.

For the group of medium-early hybrids, the average coefficient of the area leaf area surface of crop in the conditions of the research zone was 2.3 m^2/m^2 without fertilizers; 2.77 (+20.4%) and 3.34 m^2/m^2 (+45.2%) with the application of $N_{45}P_{45}K_{45}$ and $N_{90}P_{90}K_{90}$, respectively.

A gradual increase in the sowing density from 45 to 55 and 65 thousand/ha was accompanied by an increase in the indicator from 2.56 to 2.82 and 3.04 m^2/m^2, which was +10.1 and +28.7% respectively

It was established that the main parameter that determined the dynamics of changes in the indicators of the leaf apparatus of plant and crop was the area of one leaf. The determining factor in the dynamics of this indicator was the genotype (the strength of the factor's influence was 67.8%); the influence of fertilizer and density factors was 11.8 and 6.4% respectively.

The group of hybrids with high indicators of the leaf area (> 2.8 dm^2) included: Yason; Agent and LG 53.77. The minimum indicators of 1.7 dm^2 were the Phenomenon hybrid.

A statistically significant difference was noted in the response of hybrids to changes in fertilizer rates and sowing density. In variants with maximum factor values ($N_{90}P_{90}K_{90}$ and 60.0 thousand/ha), the difference between the control variant was 100% or more for the Yason, LG 53.77 and Agent hybrids; more than 60% for the Oscar and Zlatson hybrids.

The minimum response to the influence of factors was noted in the Dobrodiy (+44.2%) hybrids, Teo (+43.1%), Nabir (+42.3%) and Phenomen (+32.1%).

It was calculated that the dominant role in the change in yield indicators under favorable conditions (2019) was played by the hybrid factor (the share of the factor's influence was 60.2%). In less favorable conditions (2020 and 2021), the influence of the hybrid factor decreased. The opposite dynamics was observed for the mineral fertilizer factor, the impact of which increased in less favorable years.

REFERENCES

1. Aboye, B.M., Edo, M. (2024). Exploring genotype by environment interaction in sunflower using genotype plus genotype by environment interaction (GGE) and best linear unbiased prediction (BLUP) approaches. *Discovery Applied Science,* N.6, P.431. https://doi.org/10.1007/s42452-024-06136-1
2. Alzamel, N. M., Taha, E.M.M., Bakr, A. A. A., & Loutfy, N. (2022). Effect of organic and inorganic fertilizers on soil properties, growth yield, and physiochemical properties of sunflower seeds and oils. *Sustainability,* N.14. 12928. https://doi.org/10.3390/su141912928
3. Ansarifard, I., Mostafavi, K., Khosroshahli, M., Reza Bihamta, M., Ramshini, H. (2020). A study on genotype–environment interaction based on GGE biplot graphical method in sunflower genotypes (Helianthus annuus L.) *Food Science Nutrition*., N.8, P.3327–3334. https://doi.org/10.1002/fsn3.1610
4. Baranskyi, D. (2024). Managing sunflower growth in the changing climate and fluctuating moisture levels of the western forest-steppe. *Bulletin of Lviv National Environmental University. Series Agronom*y, N.28, P.57–66. https://doi.org/10.31734/agronomy2024.28.057
5. Beteri, J., Lyimo, J.G. & Msinde, J. V. (2024). The influence of climatic and environmental variables on sunflower planting season suitability in Tanzania. *Sci Rep*. N14, 3906. https://doi.org/10.1038/s41598-023-49581-5
6. Chen, X., Zhang, H., Teng, A., Zhang, C., Lei, L., Ba, Y. B., & Wang, Z. (2023). Photosynthetic characteristics, yield and quality of sunflower response to deficit irrigation in a cold and arid environment. *Frontiers in Plant Science*, N14. 1280347. https://doi.org/10.3389/fpls.2023.1280347
7. Clapco, S., Gisca, I., Cucereavii, A., & Duca, M. (2019). Analysis of yield and yield related traits in some sunflower (H. annuus) hybrids under conditions of the Republic of Moldova. *Agro Life Scientific Journal*, N. 8(2), P.248-258.
8. Dar, J. S., Cheema, M. A., Rehmani, M. I. A., Khuhro, S., Rajput, S., Virk, A. L., et al. (2021). Potassium fertilization improves growth, yield and seed quality of sunflower (Helianthus annuus L.) under drought stress at different growth stages. PLoS One, N.16(9), e0256075. https://doi.org/10.1371/journal.pone.0256075
9. Duca, M., Port, A., Burcovschi, I., Joiţa-Păcureanu, M. & Dan, M. (2022) Environmental response in sunflower hybrids: a multivariate approach. *Romanian Agricultural Research*. 39.139-152. DOI:10.59665/rar3914
10. Ebrahimian, E., Seyyedi, S. M., Bybordi A. & Damalas, C. A. (2019). Seed yield and oil quality of sunflower, safflower, and Sesame under different levels of irrigation water availability. *Agriculture Water Management*, N. 218, P.149–57.
11. Ghaffari, M., Gholizadeh, A., Rauf, S., & Shariati, F. (2023). Drought-stress induced changes of fatty acid composition affecting sunflower grain yield and oil quality. *Food Science & Nutrition*, N.11(12), P.7718–7731. https://doi.org/10.1002/fsn3.3690
12. Gordeyeva, Y. et al. (2023). Sunflower (Helianthus annuus) yield and yield components for various agricultural practices (sowing date, seeding rate, fertilization) for steppe and dry steppe growing conditions. *Agronomy*. DOI:10.3390/agronomy14010036
13. Haj, S.A., Khaeim, H., Tarnawa, Á., Kovács, G. P, Gyuricza, C., & Kende, Z. (2023). Germination and seedling development responses of sunflower (*Helianthus annuus* L.) seeds to temperature and different levels of water availability. *Agriculture,* N.13, P.608. https://doi.org/10.3390/agriculture13030608
14. Haque, M. A. (2024). Improving sunflower yield through liming and phosphorus fertilizer application in the south-central coastal region of Bangladesh. *Journal of the Bangladesh Agricultural University*, N.22 (3), P.352–359. https://doi.org/10.3329/jbau.v22i3.76408
15. Hanhur, V., & Kosminskyi, O. (2023). Formation of the photosynthetic-active surface of sunflower hybrid plants depending on fertilizer standards. *Scientific Progress & Innovations,* N.26 (2). P.5–9. https://doi.org/10.31210/spi2023.26.02.01
16. Harbar, L., & Vandzhura, M. (2025). Assessment of agrometeorological conditions for growing sunflower hybrids. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, N.21(5), P.98-113. doi: 10.31548/dopovidi/5.2025.98.

17. Hussain, S., Khalili, A., Qayyum, A. et al. (2025) Optimizing sunflower (Helianthus annuus L.) hybrids growth, achene and oil yield through soil applied sulphur and zinc. *Scientific Reports*, N.15, P.13829. DOI: 10.1038/s41598-025-96800-2
18. Joseph, C. O., Kambwily, K., & Emmanuel, S. M. (2025). Effects of planting window on grain yield and oil yield under rainfed sunflower (Helianthus annuus L.) in Kilwa District, Lindi, Tanzania. *Discovery Agriculture*., N.3, https://doi.org/10.1007/s44279-025-00155-1
19. Kalambet, V. (2025). Formation of sunflower productivity (Helianthus annuus L.) depending on agrotechnical methods. *Scientific Progress & Innovations*, N.28(2), P.81–86. DOI: 10.31210/spi2025.28.02.13
20. Kalenska, S., Ryzhenko, A., Novytska, N., Garbar, L., Stolyarchuk, T., Kalenskyi, V., & Shytiy, O. (2020) Morphological features of plants and yield of sunflower hybrids cultivated in the northern part of the Forest-Steppe of Ukraine. *American Journal of Plant Sciences,* N.11, P.1331-1344. https://doi.org/10.4236/ajps.2020.118095
21. Kafle, R. (2024). Nitrogen fertilizer placement and rate impacts sunflower seed yield, oil and protein content. Electronic Theses and Dissertations. 1352. https://openprairie.sdstate.edu/etd2/1352
22. Khalifani, S., Darvishzadeh, R., Mostafavi Amjad, S. H., Shayesteh, M. G., Akbari, N., Arzhang, S., & Azizi, S. M. (2026). Prediction of oil yield in sunflower using deep learning regression algorithm under normal and drought stress conditions. *BMC Plant Biology*, N.26, P.365. https://doi.org/10.1186/s12870-026-08110-y
23. Khurana, S. & Singh, R. Sunflower (*Helianthus annuus*) Seed. (2021). In: Tanwar B, Goyal A. (eds) Oilseeds: Health Attributes and Food Applications. Singapore: Springer; 123–43. https://doi.org/10.1007/978-981-15-4194-05.
24. Kohut, I. M., Valentiuk, N. O., & Shchetinikova, L. A. (2020). The formation of productiveness of the sunflower depending on the spacing of the plants in the conditions of the Southern Steppe of Ukraine. *Taurian Scientific Herald*, N.112, P.93–98. https://doi.org/10.32851/2226-0099.2020.112.13
25. Lykhochvor, V., Kvitko, A., & Vynnytskyi, V. (2024). Influence of sunflower (Helianthus annuus) sowing dates on its productivity in the Western Forest-Steppe. *Bulletin of Lviv National Environmental University. Series Agronomy*, 28. 074. DOI: 10.31734/agronomy2024.28.074
26. Lykhochvor, V., Husak, M. (2022). Yield of sunflower (Helianthus annuus) hybrids depending on sowing dates in the Western Forest-Steppe. *Bulletin of Lviv National Environmental University. Series Agronom*y, N.26, 057. DOI: 10.31734/agronomy2022.26.057
27. Ma'ali, M., Nicolene, C., William, M., & Jan, E. (2024). The impact of planting dates and hybrid selection on sunflower grain yield and oil yield. *SA Journal Plant Soil*, N. 41(1), P.1–10. https://doi.org/10.1080/02571862.2024.2352174.
28. Polyakov, O. I., & Shcherbak, A. D. (2022). Productivity of sunflower under the influence of mineral fertilizers and growth regulators. Scientific and Technical *Bulletin of the Institute of Oilseed Crops NAAS*, N.33, P.111–122. https://doi.org/10.36710/ioc2022-33-11
29. Priya Sharma, Karle, A. S., Jadhav, A.T., Rajkumar, C. & Choudhari, B. K. (2024). Influence of micronutrients on growth and productivity of kharif sunflower (Helianthus annuus L.). *International Journal of Research Agronomy,* N.7(3), P.690-693. DOI: 10.33545/2618060X.2024.v7.i3i.500
30. Puttha, R., Venkatachalam, K., Hanpakdeesakul, S., Wongsa, J., Parametthanuwat, T., Srean, P., Pakeechai, K. & Charoenphun, N. (2023). Exploring the potential of sunflowers: agronomy, applications, and opportunities within bio-circular-green economy. *Horticulturae.* N.9(10), P.1079. https://doi.org/10.3390/horticulturae9101079
31. Radic, V., Mrđa, J., Jockovic, Mi., Canak, P., Dimitrijevic, Al. & Jocic, S. (2013). Sunflower 1000-seed weight as affected by year and genotype. *Ratarstvo i Povrtarstvo,* N. 50(1), P.1-7. doi:10.5937/ratpov50-3214
32. Radu, I., & Gurau, L. R. (2023a). Influence of sowing time on morphological characteristics of sunflower plants. *Scientific Papers. Series A. Agronomy*, N.LXV(1), P.509– 513.
33. Rauf, S., Ortiz, R., Shehzad, M., Haider, W., & Ahmed, I. (2020). The exploitation of sunflower (*Helianthus annuus* L.) seed and other parts for human nutrition, medicine and the industry. *Helia*, N.43, P.167–84.
34. Riaz, A., Iqbal, M., Fiaz, S., Chachar, S., Amir, R., & Riaz, B. (2020). Multivariate analysis of superior Helianthus annuus L. genotypes related to metric traits. *Sains Malaysiana*, N.49(3), P.461-470.
35. Schmidt, E., & Silva, P. R. F. (2014). Effect of density and arrangement of plants of sunflower II. Agronomic characteristics and interception of solar radiation. *Pesquisa Agropecuaria Brasileira*, N.21(8), P.853–863. https://doi.org/10.1590/S1678-3921.pab1986.v21.14928
36. Sefaoglu, F., Ozturk, H., Ozturk, E., Sezek, M., Toktay, Z., & Polat, T. (2021). Effect of organic and inorganic fertilizers or their combinations on yield and quality components of oil seed sunflower in a semi-arid environment. *Turkish Journal of Field Crops,* N.26 (1). P.88–95. https://doi.org/10.17557/tjfc.869335
37. Shokalo, N. S., & Svystun, I. P. (2023). Sunflower yield formation depending on the seeding rate. *Taurian Scientific Herald,* N.134, P.202–207 https://doi.org/10.32782/2226-0099.2023.134.26
38. Totskyi, V., Hanhur, V.,& Poliakov, I. (2024). Yield and quality of seed of sunflower hybrids (Helianthus annuus L.) depending on the fertilizer system. *Scientific Progress & Innovations,* N.27(3). DOI: 10.31210/spi2024.27.03.01
39. Trotsenko, V. I. & Zhatova, G. O. (2018). Parameters of photosynthetic sunflower apparatus in varieties models for the area of the northeast Forest-Steppe and Polissia. *Visnik Sumskogo NAU*, N.8(35), P.53–58.
40. Yasar, M., Makalesi, A. & Cil, A.N. (2023). Investigation of genotype × environment interaction in some sunflower (Helianthus annuus L.) genotypes in different environmental conditions. *MAS Journal of Applied Sciences*, N.8(1), P.42–55. https://doi.org/10.5281/zenodo.7642289

According to the Scientific Edition
Candidate of Biological Sciences, Professor
Tetiana Melnyk

Monograph

GREEN INFRASTRUCTURE, FOREST AND AGRICULTURAL SYSTEMS: DEVELOPMENT AND RESTORATION UNDER CONTEMPORARY CHALLENGES

Published: 05.05.2026.
Typeface: Times New Roman.
RS Global Sp. z O.O., Warsaw, Poland, 2026
Numer KRS: 0000672864
REGON: 367026200
NIP: 5213776394