SOIL PREPARATION FOR CANADIAN POPLAR (*POPULUS×EURAMERICANA*) FELLING AREAS: DEVELOPMENT TRENDS AND SUSTAINABILITY CHALLENGES

[1]Tímea Makszim Györgyné Nagy - [2]György Makszim - [3]Béla Lukács - [4]Béla Szabó - [5]Andrea Györgyiné Kovács

[1] University of Nyíregyháza, Institute of Applied Humanities, H-4400 Nyíregyháza, Sóstói Str. 31/b. makszim.gyorgyne@nye.hu
[2] Piragro Kft., H-4375 Piricse, Mihály Táncsics Str. 13. makszimg@gmail.com
[3] University of Nyíregyháza, Institute of Linguistics and Literary Studies, H-4400 Nyíregyháza, Sóstói Str. 31/b. lukacs.bela@nye.hu
[4] University of Nyíregyháza, Institute of Engineering and Agricultural Sciences, H-4400 Nyíregyháza, Sóstói Str. 31/b. szabo.bela@nye.hu
[5] University of Debrecen, IAREF, Research Institute of Nyíregyháza, H-4400 Nyíregyháza, Westsik Vilmos Str. 4-6. gyorgyine@agr.unideb.hu

https://doi.org/10.71066/FTTMK.2.28

Introduction

The economic and ecological roles of growing Canadian poplar in Hungary are significant, especially in terms of producing industrial timber, biomass for energy purposes, and carbon sequestration. The successfulness of clearing reforestation is largely influenced by the technology used in soil preparation. The aim of this study is the comparison of the traditional and innovative methods of soil preparation used in the felling areas of Canadian poplar as well as the sustainability-oriented assessment of such technologies. The results indicate that classic technologies based on intensive cultivation lead to a considerable ecological impact, while more recent solutions, especially forestry tillers, reduced tillage, and biological stump decomposition technologies, display a more improved environmental impact. Establishing a balance between productivity and ecology is one of the biggest challenges for forestry in the future.

Literature review

Climate change, soil degradation, and the need for using natural resources in a sustainable manner have been a growing challenge for forestry. The rising frequency of extreme weather events, the change in precipitation distribution, and the increase in temperature have been affecting the stability of the forest ecosystems and their natural regenerating capability (Lindner et al., 2010; Vágvölgyi & Kosztyuné Krajnyák, 2025). A key element of sustainable forestry is the appropriate preparation of the felling areas, which is fundamental in the development of the young trees as well as the survival ratio of the seedlings and the long-term fertility of the site (Bárány, 2012; Kosztyuné Krajnyák, 2022). The purpose of soil preparation is to ensure favourable physical, chemical, and biological conditions for afforestation. The properly-selected tilling technologies will improve soil absorbency and soil water retention capacity, decrease the extent of weed encroachment, and facilitate the quicker development of roots (Buzás, 1998, Kosztyuné Krajnyák, 2021). At the same time, excessive or inappropriate soil disturbance can increase erosion, degrade soil structure, and contribute to a decline in organic matter content, which has a negative long-term impact on the functioning of the forest ecosystem (Jandl et al., 2007; Vágvölgyi et al., 2016). In recent decades, sustainable forest management has placed an increasing emphasis on site preparation methods that ensure effective forest regeneration while minimizing environmental impact. Therefore, modern forestry practices favour the use of site-specific technologies, taking into account soil type, topography, water balance, and expected climate changes (MCPFE, 2003). Implementing soil conservation measures in nature-oriented forest management improves forest stability, conserves biodiversity, and maintains ecosystem services. In addition to timber production, forests provide habitats for numerous protected plant species; therefore, sustainable forest management supports not only soil functions but also the conservation of biodiversity, including endangered flora (Csabai et al., 2011; Farkas et al., 2025;

Szarvas et al., 2025; Duncker et al., 2012). Furthermore, soil disturbance associated with logging operations may facilitate the establishment and spread of invasive plant and insect species, highlighting the importance of monitoring and preventive management to preserve biodiversity and ecosystem stability (Csecserits et al., 2018; Takács et al., 2022). Consequently, the preparation of logging sites is no longer merely a technological task but a key component of sustainable forest management, influencing the ecological and economic value of forests in the long term.

The cultivation significance of Canadian poplar

The Canadian poplar (*Populus×euramericana*) is one of Hungary's most important fast-growing tree species, which, under favourable growing conditions, features a short rotation period and high biomass production. Its significant economic value stems from its rapid growth, high-quality wood, and versatility, making it one of the most important tree species in intensive timber production systems (Mátyás, 2004). At the same time, intensive farming requires increased attention to preserving the characteristics of the growing area, maintaining the physical and biological condition of the soil, and minimizing environmental impacts (FAO, 2016). In suitable growing conditions, the Canadian poplar can be grown economically with a rotation period of 20–25 years. It has exceptionally high light, water, and nutrient requirements; therefore, it achieves outstanding growth primarily on alluvial and meadow soils with deep topsoil and good water management (Bárány, 2012). Adequate soil moisture and nutrient supply are essential for rapid initial growth, which significantly determine the stand's subsequent development and the harvestable timber volume (Dickmann & Kuzovkina, 2014). The root system of the Canadian poplar is sensitive to soil compaction and anaerobic soil conditions; therefore, it is particularly important to preserve soil structure and use appropriate soil preparation techniques (Jandl et al., 2007).

In Hungary, Canadian poplar stands play a key role in industrial timber production, particularly in supplying raw materials to the paper and pulp industry, particleboard and plywood manufacturing, the pallet industry, and biomass production for energy purposes. Moreover, they play a significant ecological role, as their rapid growth allows them to sequester substantial amounts of carbon dioxide, thereby contributing to the mitigation of climate change (IPCC, 2022). Short-rotation Canadian poplar plantations are therefore important components of the circular bioeconomy and renewable raw material production in Europe (FAO, 2016). The proportion of Canadian poplar in Hungary's forest areas has declined in recent decades, while cultivation techniques have undergone significant advancements. The use of new clones, modern soil preparation methods, precision planting technologies, and site-specific management have all contributed to increased productivity and improved stand stability (*Országos Erdőállomány Adattár* [National Forestry Database], 2024). However, as a result of climate change, there is a growing emphasis on farming practices that improve soil water retention, reduce drought stress, and promote the long-term adaptability of crops (Lindner et al., 2010). Accordingly, soil-conserving forestry techniques and proper soil preparation are fundamental not only to the success of initial establishment but also to the economic viability and sustainability of Canadian poplar plantations.

Changes in the tree species composition of Hungary's forests between 2005 and 2024

To assess the domestic significance of Canadian poplar cultivation, we need to examine changes in the composition of Hungary's forest stands by tree species group over the past two decades. Changes in the spatial distribution of individual tree species groups clearly illustrate the structural changes that have taken place in forest management, as well as the economic, conservation, and climate adaptation processes influencing the roles of individual tree species in the country's forest stands (see Table 1).

According to data from the *Országos Erdőállomány Adattár*, Hungary's forest area increased from 1,789,673 hectares to 1,882,059 between 2005 and 2024, representing an increase of 92,386 hectares, or nearly 5.2 per cent. This growth is primarily attributable to afforestation efforts and domestic and European Union programs aimed at increasing forest cover (Makszim et al., 2024).

Among tree species groups, acacia *(Robinia pseudoacacia)* continues to cover the largest area; its stand increased from 413,876 hectares to 462,504, and its share rose from 23 per cent to 25. A significant increase in area can also be observed for oak *(Quercus)*, Turkey oak *(Quercus cerris)*, and other hardwood species, indicating a gradual strengthening of the role of native species.
However, Canadian poplar, which is of particular importance for this study, has showcased a decline. The area covered by Canadian poplar decreased from 125,363 hectares to 96,106, representing a reduction of approximately 29,000 hectares, or nearly 23 per cent. As a result, its share of the country's total forest area fell from 7 per cent to 5. There may be several factors behind this change, including the growing prevalence of near-natural forest management, the prioritization of native tree species, and the gradual conversion of Canadian poplar stands located in unsuitable habitats.
At the same time, the Hungarian area of poplar stands has increased significantly (from 61,155 hectares to 100,973), which clearly reflects the growing use of native poplar species. In contrast, conifer stands have experienced a significant decline, with their area decreasing from 226,356 hectares to 170,241, a trend that can be linked to the adverse effects of climate change and the decline of climate-sensitive tree species.

Table 1. The distribution of Hungary's forest stock by tree species group in 2005 and 2024

Tree Species Group	2005		2024	
	Hectares	**%**	**Hectares**	**%**
Oak	371,973	21	395,027	21
Turkey oak	199,907	11	219,795	12
Beech	106,487	6	114,010	6
European hornbeam	94,315	5	99,012	5
Acacia	413,876	23	462,504	25
OHB	90,647	5	128,753	7
Canadian poplar	**125,363**	7	**96,106**	5
Native poplar	61,155	3	100,973	5
Willows	22,705	1	17,457	1
Other soft broadleaves	76,890	4	78,180	4
Conifer	226,356	13	170,241	9
Total	**1,789,674**	100	**1,882,058**	100

Source: Országos Erdőállomány Adattár, 2024

Overall, the data in the table show that, although the Canadian poplar remains a tree species of significant economic importance in Hungary, its share has declined over the past two decades. This further underscores the importance of using modern, soil-conserving site preparation technologies in both existing and newly planted Canadian poplar plantations, as these contribute to the long-term sustainability of the site, the stable development of the stands, and the assurance of economically viable timber production.

The characteristics of soil conditions in the felling areas

After the felling of timber, the soil in felling areas undergoes significant physical, chemical, and biological changes that fundamentally influence the success of forest regeneration and the development of the new stand. The heavy machinery used during logging operations, logging technologies, and the presence of stumps and logging residues significantly alter the soil's structure and function (Ampoorter et al., 2012).
The most significant physical change is soil compaction, which occurs primarily as a result of repeated passage of heavy forestry machinery. In compacted soil, pore volume decreases, air and water management deteriorates, and the soil's mechanical resistance increases, which hinders root development and reduces water infiltration (Horn et al., 2007). Soil compaction reduces the survival rate of seedlings, slows their initial growth, and increases their susceptibility to drought, particularly during dry periods that have been becoming more frequent as a result of climate change (Ampoorter et al., 2012). The stumps, root remnants, and other plant parts left behind after logging can have both positive and negative effects on the site. In the long term, the

decomposition of organic matter contributes to humus formation and nutrient replenishment; however, it also significantly complicates planting operations, hinders the work of soil-tilling machinery, and can provide a favourable habitat for certain pests and pathogens (Matthews, 1991). Therefore, in many cases it becomes necessary to partially remove stumps or to carry out targeted soil preparation between rows.

A temporary decline in soil nutrient levels is also frequently observed in felling areas. Logging results in the removal of significant amounts of organic matter and mineral nutrients from the ecosystem, while increased mineralization and erosion processes can further exacerbate nutrient loss (Jandl et al., 2007). A decline in nutrient availability can cause problems, particularly with regard to nitrogen and potassium supply, which adversely affects the growth of young plantations.

Logging also has a significant impact on the biological properties of the soil. Changes in soil structure, alterations in the microclimate, and shifts in organic matter cycling can lead to a decrease in soil microbiological activity, as well as a reduction in the species richness of fungi and bacteria (Prescott & Grayston, 2013).

Together, the physical, chemical, and biological changes listed above significantly determine the success of forest regeneration. For this reason, selecting the appropriate soil preparation technology not only improves seedling establishment but also contributes to restoring soil structure, improving water balance, and preserving soil biological activity. The use of modern, site-specific, and soil-conserving cultivation methods is therefore a fundamental requirement of sustainable forest management (MCPFE, 2003).

The purpose of soil preparation

Soil preparation is one of the most important technical operations in afforestation and reforestation, the primary purpose of which is to create favourable soil conditions that ensure the successful establishment, rapid initial development, and long-term growth of young seedlings. A well-prepared soil improves root penetration, promotes water and nutrient uptake, and creates favourable conditions for biological processes in the soil (Matthews, 1991).

One of the most important goals of soil preparation is to promote root development. During the early stages of young trees' growth, rapid root development determines the efficiency of water and nutrient uptake, as well as the plant's stability. Soil with a looser structure exerts less mechanical resistance on the roots, allowing them to penetrate deeper, access a larger soil volume, and better withstand dry periods (Bengough et al., 2011). Rapid root development is particularly important for the Canadian poplar, as the species' vigorous growth requires a significant supply of water and nutrients.

Another key objective of soil cultivation is to improve soil structure. Appropriate cultivation practices reduce the formation of compacted layers, increase the ratio of macro- to micropores, and thereby improve the soil's air and water management (Horn & Fleige, 2009). Well-structured soil provides a more favourable environment for soil-dwelling microorganisms, which play a key role in the decomposition of organic matter and the release of nutrients (Brady & Weil, 2017).

Proper soil preparation also helps improve the soil's water absorption and retention capacity. Greater pore volume promotes faster infiltration of precipitation, reduces surface runoff, and lowers the risk of erosion. In addition, soil with good water management can provide moisture available to plants for a longer period of time, which is particularly important during increasingly frequent periods of drought (Lal & Shukla, 2004). Adequate water supply not only increases the survival rate of seedlings but also promotes photosynthetic activity and biomass production.

Another important goal of soil preparation is to promote better nutrient utilization. In soil with a favourable structure and adequate aeration, microbiological activity is more intense, the mineralization of organic matter is faster, and the conversion of nitrogen, phosphorus, and potassium compounds into available forms becomes more efficient (Brady & Weil, 2017). In addition, suitable soil conditions promote the development of mycorrhizal fungi, which significantly improve the uptake of nutrients and water by woody plants.

In forestry practice, soil is considered ideal if it is crumbly, has a loose structure, possesses an appropriate pore distribution, is sufficiently aerated, and at the same time provides good water-retaining capacity. In such soil, water, air, and heat management are balanced, creating favourable conditions for root development and the maintenance of soil life (Stefanovits et al., 2010). In modern forest management, therefore, when selecting soil preparation technologies, it is necessary to take into account the physical properties of the soil, the characteristics of the site, and the effects of expected climate change, so that these interventions ensure the stable development of forest stands on the long run (FAO, 2016).

Material and method

This study is based on a literature review aimed at summarizing the soil preparation technologies used in the felling areas of Canadian poplar plantations, as well as their implications for soil conservation and sustainability. To prepare the review, domestic and international literature sources have been analyzed, including textbooks, peer-reviewed scientific journal articles, and official publications from international organizations (FAO, IPCC) and Hungarian institutions (*Országos Erdőállomány Adattár*). To assess changes in Hungary's forest stock by tree species group, a comparative analysis of national forest resource statistics from 2005 and 2024 was conducted. The synthesis of the collected information enabled a comparative assessment of the advantages, limitations, and sustainability aspects of traditional and modern soil preparation technologies, as well as an overview of future development directions for Canadian poplar cultivation.

Results and assessment

1. Traditional soil preparation technologies

The goal of soil preparation in felling areas is to create favourable site conditions that promote the successful establishment and development of the new forest stand. The development of traditional technologies was primarily driven by the needs of intensive forest management, which prioritized rapid and uniform afforestation. Although these methods have effectively served timber production for a long time, research findings highlighting the long-term ecological consequences of significant soil disturbance have increasingly come to the fore in recent years (Matthews, 1991; Jandl et al., 2007).

a) Stump turning and deep plowing

In traditional forest regeneration, the first step following logging is the mechanical removal of stumps. The removed stumps are usually arranged in longitudinal rows or pushed to the edge of the area; this is followed by deep plowing , loosening the subsoil, and levelling the surface (see Picture 1). The goal is to create a homogeneous soil condition suitable for planting seedlings and for subsequent mechanical maintenance work (Bárány, 2012).

Picture 1. Stump turning and deep plowing
Source: Image made by AI

The most important advantage of this technology is that it completely eliminates obstacles caused by stumps and thicker root remnants. The loosened soil provides favourable conditions for the initial development of roots, improves the establishment of seedlings, and simplifies subsequent mechanical weed control and maintenance work (Matthews, 1991).

However, this method has a significant environmental impact. Extensive soil disturbance can degrade the soil's natural structure, reduce its organic matter content, and increase carbon dioxide emissions from the soil. Deep tillage can also adversely affect soil microbial communities, as the mixing of the humus-rich topsoil with the underlying soil layers alters the living conditions of microorganisms (Jandl et al., 2007; Brady & Weil, 2017).

Another problem is that rows of stumps can remain in the area for many years. These can hinder subsequent cultivation work, while also altering local water balance and microclimatic conditions. On steeper slopes, full-depth tillage increases the risk of erosion, especially during intense rainfall events (Lal & Shukla, 2004).

b) Stump grinding

In recent decades, stump grinding technology has become increasingly widespread as an alternative to stump removal. The method involves using special grinders to break up stumps near the surface, after which the chipped wood is either left in the soil or transported away for energy recovery (see Picture 2).

One of the greatest advantages of this process is that it eliminates the obstacles posed by large stumps, while yielding a significant amount of biomass that can be utilized as a renewable energy source. Stump grinding is particularly advantageous where the use of biomass for energy can be economically viable (Spinelli et al., 2019).

The main drawback is the high purchase and operating costs of high-performance specialized machinery. In addition, frequent vehicle traffic can increase the risk of soil compaction, especially in wet soil conditions (Ampoorter et al., 2012).

Picture 2. Stump grinding
Source: Image made by AI

2. Modern solutions for soil preparation

With the growing popularity of sustainable forest management, technologies ensuring effective forest regeneration while preserving the physical and biological condition of the soil have come increasingly to the fore. A common feature of these technologies is that they involve less soil disturbance, lower energy consumption, and a reduced environmental impact.

a) Using forestry tillers

Forestry tillers are among the most advanced soil-preparation machines available today. During operation, the rotating mulching blades shred stumps, root remnants, and other plant debris, then mix them into the top 30–50 cm layer of soil. At the same time, they loosen and homogenize the soil, thereby creating favourable planting conditions (see Picture 3).

Picture 3. Forestry tiller
Source: Image made by AI

The most important advantage of this technology is that the organic matter remains on-site, thereby increasing humus content in the long term and improving soil structure and water retention capacity. Since there is no need to transport stumps, energy consumption and carbon dioxide emissions from transportation are also reduced (FAO, 2016). The use of tillers is increasingly aligned with the circular bioeconomy approach, which prioritizes the local utilization of biomass.

b) Stump drilling and biological decomposition

One of the latest areas of research focuses on accelerating the natural decomposition of tree stumps. This involves drilling holes into the stumps and introducing lignin-degrading fungi or other microbial products into them. The goal of this method is to accelerate the decomposition of the wood and gradually return the organic matter to the soil (Asiegbu et al., 2005).
This technology involves minimal soil disturbance, so it has a positive effect on soil structure and microbiological activity. Since there is no need for large-scale earthworks, fossil fuel consumption and greenhouse gas emissions can also be significantly reduced. Although the method is currently used primarily in experimental or specialized applications, it could play an important role in nature-oriented forest management in the long term.

Picture 4. Stump drilling and biological decomposition
Source: https://kormendi-online.hu/HU/569

3. Trends in forest soil management

In recent years, developments in forest soil management have been driven primarily by digitalization, sustainability, and climate adaptation. Precision forest management allows soil preparation measures to be tailored to the specific conditions of the site. With the help of GPS-based machine guidance, drone surveys, LiDAR technology, and soil sensor systems, it is possible to more accurately identify areas where more or less intensive intervention is needed (MCPFE, 2003; Shokirov et al., 2025).
Reduced tillage is also receiving increasing attention, as it aims to preserve soil structure and soil life. Such technologies mitigate the loss of organic matter from the soil, reduce erosion, and improve the soil's carbon sequestration capacity (Lal, 2020).
One promising direction for the future is the development of agroforestry systems, in which woody plants are combined with agricultural crops. These systems improve biodiversity, increase soil organic matter content, mitigate extreme microclimatic effects, and enhance the ecosystem's resilience to climate change (Jose, 2009).

4. Sustainability challenges

Among the most significant challenges facing the cultivation of Canadian poplar are soil degradation, declining biodiversity, worsening water management problems, the depletion of nutrient reserves, and the increasing frequency of extreme weather events resulting from climate change (IPCC, 2022). The increase in periods of drought, the more frequent occurrence of heat waves, and the uneven spatial and temporal distribution of precipitation pose an ever-greater challenge to the cultivation of fast-growing tree species.
Sustainable forest management, therefore, requires the use of soil preparation technologies that simultaneously ensure economical timber production, the long-term preservation of soil fertility, and the maintenance of ecosystem services. Future forestry technologies are expected to focus on soil-conserving cultivation systems, precision machinery, on-site utilization of biomass, and the support of natural soil biological processes, all of which can contribute to the implementation of sustainable forestry adapting to climate change.

Conclusion

Based on a review of the literature, it can be concluded that soil preparation plays a decisive role in the successful establishment of Canadian poplar plantations and in maintaining their long-term productivity. Ensuring proper soil conditions promotes root development, improves water and nutrient uptake, and contributes to seedling establishment and initial growth. In contrast, soil compaction, deterioration of soil structure, and a decline in soil biological activity following logging can adversely affect the success of forest regeneration.

Traditional soil preparation technologies, particularly stump turning and deep plowing, remain effective solutions for preparing sites for planting; however, they involve significant soil disturbance, high energy consumption, and increased environmental impact. Modern methods, such as the use of forestry tillers or techniques that promote the on-site biological decomposition of stumps, offer a more favourable alternative, as they minimize damage to soil structure, promote the on-site utilization of organic matter, and contribute to the preservation of soil health.
As a result of climate change and the expectations placed on sustainable forest management, soil preparation technologies that simultaneously ensure economical timber production and the long-term conservation of the site are becoming increasingly important. In future forestry practices, the role of soil-conserving cultivation systems, precision technologies, and circular biomass utilization is expected to continue to grow; the combined application of these approaches can contribute to increasing the economic efficiency and ecological sustainability of Canadian poplar cultivation.

Summary

This study reviews soil preparation techniques for felling areas of Canadian poplar plantations from the perspective of sustainable forest management. It describes changes in soil conditions after felling and their impact on the effectiveness of forest regeneration. It describes traditional soil preparation methods, with particular emphasis on stump removal, deep plowing, and stump grinding, and evaluates their advantages and limitations. In addition, it reviews modern, soil-conserving solutions, such as the use of forestry tillers and the biological decomposition of stumps. Based on the findings in the literature, it can be concluded that soil-conserving technologies contribute to the preservation of soil structure and soil life, reduce environmental impact, and support sustainable biomass production. Due to climate change and changes of site conditions, site-specific, precision, and circular soil preparation systems are playing an increasingly important role in future forest management, as they serve to balance economic efficiency with ecological sustainability.

Keywords: sustainable forest management, soil condition, stump drilling, biological decomposition

Bibliography

Ampoorter, E., Van Nevel, L., De Vos, B., Hermy, M., & Verheyen, K. (2012). Assessing the effects of initial soil characteristics, machine mass and traffic intensity on forest soil compaction. Forest Ecology and Management, 267, 107–114. https://doi.org/10.1016/j.foreco.2011.11.022

Asiegbu, F. O., Adomas, A., & Stenlid, J. (2005). Conifer root and butt rot caused by Heterobasidion annosum (Fr.) Bref. Molecular Plant Pathology, 6(4), 395–409. https://doi.org/10.1111/j.1364-3703.2005.00295.x

Bárány, S. (2012). Erdőművelés tan. Soproni Egyetem Kiadó.

Brady, N. C., & Weil, R. R. (2017). The Nature and Properties of Soils (15th ed.). Pearson.

Buzás, I (Szerk.). (1998). Talaj- és agrokémiai vizsgálati módszerkönyv 2. Fizikai-kémiai és kémiai vizsgálati módszerek. Mezőgazda Kiadó.

Csabai, J., Nagy, Z., & Mándy, A. T. (2011). In vitro shoot proliferation of Telekia speciosa (Schreb.) Baumg. induced by different cytokinins. Acta Biologica Hungarica, 62(4), 453–462. https://doi.org/10.1556/ABiol.62.2011.4.10

Csecserits, A., Barabás, S., Csabai, J., Devescovi, K., Hanyecz, K., Höhn, M., Kósa, G., Németh, A., Orlóci, L., Papp, L., Pándi, I., Ruborits, T., Diószeginé, M., Szitár, K., Tihanyi, G., & Papp, L., Jr. (2018). Hazai botanikus kerti tapasztalatok az európai uniós inváziós listán szereplő szárazföldi növényekkel kapcsolatban. Botanikai Közlemények, 105(1), 143–154. https://doi.org/10.17716/BotKozlem.2018.105.1.143

Dickmann, D. I., & Kuzovkina, Y. A. (2014). Poplars and Willows of the World, with Emphasis on Silviculturally Important Species. Food and Agriculture Organization. https://doi.org/10.1079/9781780641089.0008

Duncker, P. S., Raulund-Rasmussen, K., Gundersen, P., Katzensteiner, K., De Jong, J., Ravn, H. P., Smith, M., Eckmüllner, O., & Spiecker, H. (2012). How forest management affects ecosystem services, including timber production and economic return: Synergies and trade-offs. Ecology and Society, 17(4), 50. https://doi.org/10.5751/ES-05066-170450

Farkas, D., Csabai, J., Kolesnyk, A., Szarvas, P., & Dobránszki, J. (2025). In vitro micropropagation protocols for two endangered Dianthus species – via in vitro culture for conservation and recultivation purposes. Plant Methods, 21, Article 13. https://doi.org/10.1186/s13007-025-01335-2

Food and Agriculture Organization. (2016). Poplars and Other Fast-Growing Trees: Renewable Resources for Future Green Economies. FAO.

Horn, R., Vossbrink, J., Peth, S., & Becker, S. (2007). Impact of modern forest vehicles on soil physical properties. Forest Ecology and Management, 248(1–2), 56–63. https://doi.org/10.1016/j.foreco.2007.02.037

Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Mitigation of Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157926

Jandl, R., Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedorn, F., Johnson, D. W., Minkkinen, K., & Byrne, K. A. (2007). How strongly can forest management influence soil carbon sequestration? Geoderma, 137(3–4), 253–268. https://doi.org/10.1016/j.geoderma.2006.09.003

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits. Agroforestry Systems, 76(1), 1–10. https://doi.org/10.1007/s10457-009-9229-7

Kosztyuné Krajnyák, E. (2021). A Nyírségben termesztett homoki növények. In C. Tóth (Ed.), Őshonos- és tájfajták – ökotermékek – egészséges táplálkozás – vidékfejlesztés: Minőségi élelmiszerek – egészséges környezet – fenntartható vidéki gazdálkodás: Az agrártudományok és a vidékfejlesztés kihívásai a XXI. században Nyíregyházi Egyetem, Műszaki és Agrártudományi Intézet, 141–149.

Kosztyuné Krajnyák, E. (2022). The importance of hairy vetch (Vicia villosa Roth) in improving the fertility of the acidic sandy soils of Nyírség. In G. L. Páy (Ed.), International Multidisciplinary Conference: 14th Edition (pp. 58–62). Nyíregyházi Egyetem.

Lal, R. (2020). Regenerative agriculture for food and climate. Journal of Soil and Water Conservation, 75(5), 123A–124A.

Lal, R., & Shukla, M. K. (2004). Principles of Soil Physics. Marcel Dekker. https://doi.org/10.4324/9780203021231

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M. J., & Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management, 259(4), 698–709. https://doi.org/10.1016/j.foreco.2009.09.023

Makszim Györgyné Nagy, T., Soós, A., Kosztyuné Krajnyák, E., Csabai, J., & Szabó, B. (2024). Az erdőgazdálkodás vármegyei szintű statisztikai elemzése 2000–2022 között, különös tekintettel a fenntartható erdőgazdálkodásra. In K. Irinyiné Oláh, E. Kosztyuné Krajnyák, B. Szabó, & E. Bara (Eds.), Fenntartható Tápanyag-gazdálkodási Tudományos Műhely Konferenciája 2024. Innovatív megoldások a XXI. század mezőgazdaságában: Konferencia kiadvány Nyíregyházi Egyetem, Műszaki és Agrártudományi Intézet, 66–73.

Matthews, J. D (1991). Silvicultural Systems. Oxford University Press. https://doi.org/10.1093/oso/9780198546702.001.0001

Mátyás, C (Szerk.). (2004). Az erdészeti ökológia alapjai. Mezőgazda Kiadó.

Ministerial Conference on the Protection of Forests in Europe. (2003). Improved Pan-European Indicators for Sustainable Forest Management. Vienna.

Országos Erdőállomány Adattár. (2024). Erdővagyon-statisztikai adatok. Nemzeti Földügyi Központ.

Prescott, C. E., & Grayston, S. J. (2013). Tree species influence on microbial communities in litter and soil: Current knowledge and research needs. Forest Ecology and Management, 309, 19–27. https://doi.org/10.1016/j.foreco.2013.02.034

Shokirov, S., Abdurahmanov, I., Mamatkulov, Z., Abdurahmanov, Z., Zarifboev, D., Oymatov, R., Kovács, Z., Csabai, J., Shiping, Y., & Khakberdiev, O. (2025). Leveraging vegetation indices and Random Forest for soil nutrient monitoring in winter wheat. Journal of the Indian Society of Remote Sensing. https://doi.org/10.1007/s12524-025-02198-9

Spinelli, R., Magagnotti, N., & Cavallo, E. (2019). Biomass recovery from stumps: Operational and environmental aspects. Biomass and Bioenergy.

Stefanovits, P., Filep, G., & Füleky, G. (2010). Talajtan. Mezőgazda Kiadó.

Szarvas, P., Farkas, D., Csabai, J., Kolesnyk, A., & Dobránszki, J. (2025). In vitro micropropagation of Dianthus plumarius subsp. praecox, a wild carnation species, for ornamental horticultural and gene conservation purposes. Scientia Horticulturae, 339, 113886. https://doi.org/10.1016/j.scienta.2024.113886

Takács, A., Szabóky, C., Tóth, B., Bozsó, M., Kutas, J., Molnár, Sz., Farkas, G., Erdélyi, K., Tunyoginé Búzás, I., Hargitai, C., Terman, N., Menyhárt, A., Bodnár, Sz., Gajdos, É., Bogya, S., Csabai, J., Molnár, B., & Nagy, A. (2022). Bionomics and host plants of the invasive Cydia interscindana (Möschler, 1866) (Lepidoptera, Tortricidae), an emerging pest in the Carpathian Lowlands. Nota Lepidopterologica, 45, 53–64. https://doi.org/10.3897/nl.45.74236

Országos Meteorológiai Szolgálat (é. n.). NDVI ismertető. https://www.met.hu/ismertetok/NDVI_ismerteto.pdf

Internetes hivatkozás: : https://kormendi-online.hu/HU/569 (letöltés dátuma: 2026.04.19.)

Images generated by artificial intelligence: AI tool: GPT-5.3; Prompt: Create an image of stump turning and deep plowing, stump grinding, and forestry tiller soil preparation methods in the Populus×euramericana felling area; Image generation purpose: illustration, visualization

Vágvölgyi, S., Borbély, F., & Kosztyuné Krajnyák, E. (2016). Az alternatív növényeknek nincs alternatívája. MAG Kutatás Fejlesztés és Környezet, 22(3), 112–115.

Vágvölgyi, S., & Kosztyuné Krajnyák, E. (2025). Savanyú homoktalajok fenntartható hasznosításának agronómiai kihívásai a környezeti változások tükrében. In J. Csajbók (Ed.), Kihívások és megoldások a szántóföldi növénytermesztésben: Prof. Dr. Pepó Péter 70 éves (pp. 222–227). Debreceni Egyetem Mezőgazdaság-, Élelmiszertudományi és Környezetgazdálkodási Kar.