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ECOMORPHIC ANALYSIS OF VEGETATION COVER OF TECHNOSOLS OF NIKOPOL MANGANESE ORE BASIN

Ecomorphic analysis, technosols, vegetation cover, soil reclamation, biodiversity, ecological conditions, mining industry

ECOMORPHIC ANALYSIS OF VEGETATION COVER OF TECHNOSOLS OF NIKOPOL MANGANESE ORE BASIN. O.V. Zhukov, N.O. Podpriatova. – The study presents data on the biodiversity of vegetation cover on technosols, which developed as a result of long-term land reclamation after open-cast mining. An ecomorphic approach was used to analyze the ecological structure of plant communities, revealing a high level of species richness. The taxonomic composition of the flora mirrors the typical structures of the regional flora. In terms of ecomorphology, steppe and ruderal ecomorphs dominate the communities. The study also evaluates the conditions of humidity, trophicity, and illumination of edaphotopes based on the ecomorphic structure of the plant communities.

ЕКОМОРФНИЙ АНАЛІЗ РОСЛИННОГО ПОКРИВУ ТЕХНОЗЕМІВ НІКОПОЛЬСЬКОГО МАРГАНЦЕВОРУДНОГО БАСЕЙНУ. О.В. Жуков, Н.О. Подпрятова. – У дослідженні представлено дані про біорізноманіття рослинного покриву техноземів, які утворилися в результаті тривалої рекультивації земель, порушених внаслідок відкритих гірничих робіт. Для аналізу екологічної структури рослинних угруповань був застосований екоморфний підхід. Виявлено високий рівень видового багатства рослинних угруповань. Таксономічний склад флори відтворює структури, типові для регіональної флори. У ценоморфному аспекті в угрупованнях переважають степанти та рудеранти. Також наведено оцінку умов вологості, трофності та освітленості едафотопів на основі екоморфної структури рослинних угруповань.

The environmental situation in the Dnipro region (Ukraine) is characterized by the widespread crisis phenomena affecting entire industrial agglomerations and mining basins (Kryvyi Rih iron ore basin, West Donbas coal basin, Nikopol-Marhanets-Pokrovsky basin, Dnipro-Kamianske-Samar and Zhovtovodsko-Pyatikhatsko-Vilnohirsk agglomerations) and adjacent territories. These disturbances result in significant soil degradation, air pollution, and accumulation of hazardous waste (Kharytonov et al., 2020; Stefanovska et al., 2022; Zhukov et al., 2018). The disturbed land area in Ukraine exceeds a million hectares, causing profound changes in natural landscapes and often radical changes in their structure (Gruss et al., 2019; Nurzhanova et al., 2019). The impact of the mining industry is often referred to as "anthropogenic orogenesis" and "catastrophic anthropogenesis" or, more precisely, "technogenic successions" (Masyuk, 1971; Pidlisnyuk et al., 2020), with the resulting man-made landscapes exerting a negative ecological effect on the environment (Alasmary et al., 2021; Izakovičová et al., 2022; Maslikova, 2018).

A significant challenge in the reclamation of industrial soil arises from the lack of scientifically sound and economically feasible technologies (He et al., 2014; Paoletti, 1999). The transformation of technogenic landscapes into natural ones is primarily driven by biological processes, leading to the formation of biogeocenosis (Ellis, 2011; Kharytonov et al., 2021). The effectiveness of reclamation, including the restoration of fertility, depends on the biological stage of reclamation (Trepanier et al., 2021). Reclamation is a complex system of activities aimed at restoring ecological balance in anthropogenically altered landscapes and creating conditions for their targeted use (Antwi et al., 2014; Drummond et al., 2015; Kuter, 2013; Nebeska et al., 2019; Zhukov et al., 2016). It also involves the restoration of the biogeocenotic cover and the establishment of a new hierarchical organization (Denysyk et al., 2021; Zhukov et al., 2017). Reclaimed soil can exceed the original soil cover in terms of functionality and fertility (Stefanovska et al., 2021). However, structurally, reclaimed soils differ significantly from their natural counterparts across all spatial and hierarchical levels (Maslikova, 2017).

To create ecologically balanced landscapes in disturbed lands, the successful integration of artificial ecotopes and biota is essential (Maslikova, 2017). The reclamation process begins with the technical stage, during which landscape adjustment and application of the fertile soil layer take place (Maslikova, 2018). Key indicators for the productivity and biota suitability of reclaimed lands include actual acidity (pH) and salinity (Yorkina et al., 2018). The biological phase of reclamation follows, focusing on soil macrofauna, particularly saprotrophic species such as earthworms, enchytreids, and millipedes, which significantly contribute to soil transformation (Maslikova, 2017; Pakhomov et al., 2019; Yorkina et al., 2019).

Technologically disturbed lands are initially unsuitable for active soil formation and remain technogenic wastelands for a long period (Alasmary et al., 2021; Valdes et al., 2012). The soil-forming rocks of man-made surface formations gradually undergo weathering, leaching, and other biological transformations into soil material (Bradshaw, 2000), but primary soil formation is slow, even in ecosystems rich in biological resources (Arora et al., 2013; Valentin-Vargas et al., 2018). Biological reclamation helps restore soil properties, but technosols cannot yet be considered true soil by Dokuchaev′s definition due to the remnants of overburden and host rocks that hinder plant survival (Maslikova, 2017; Joimel et al., 2022). These anthropogenic soils form on lifeless deep rocks brought to the Earth's surface (Bao et al., 2010; Pidlisnyuk et al., 2022). Technosols undergo active soil-forming processes and exhibit high spatial heterogeneity, which results in a regular spatial structure (Chitade, 2010). Despite the youth and unpredictability of anthropogenic ecosystems, they can be understood through bioindicators, which show certain patterns of change during succession (Maslikova, 2018; Gruss et al., 2022). Organisms, their physiological processes, and communities act as bioindicators, reflecting external environmental impacts (Nazarenko, 2016; Zhukov et al., 2019). Vegetation serves as an effective tool for assessing environmental conditions, especially in reclaimed soils (Domnich et al., 2021; Kunakh et al., 2021). The rising anthropogenic impact on the environment calls for identifying indicators to assess anthropogenically transformed ecosystems. O.L. Belgard′s ecomorphic analysis is a valuable method for describing vegetation in such contexts.

M.T. Masyuk (Masyuk, 1971) distinguishes three stages in the process of restoration of vegetation on waste dumps that are reclaimed using the technology without applying the black soil layer: the stage of pioneer community, the stage of simple community and the stage of complex community. The use of vegetation for indication allows to assess quite accurately the qualitative changes that occur in sod-lithogenic in the process of their biological development (Zhukov et al., 2019; Kunakh et al., 2018; Sattler et al., 2010). Regarding the vegetation cover of reclaimed soils, it is reasonable to assume that for the quantitative characterization of ecological diversity of vegetation to be assessed by considering the ecomorphic features of plants or their phytoindicative properties (Zymaroieva et al., 2014). Network organization of ecological relationships by its nature can be represented in the form of a hierarchical dendrogram, which made it possible to apply taxonomic diversity indices for quantitative assessment of ecological diversity. Synphytoindication has been shown to be an informative method for establishing ecological regimes in anthropogenically transformed ecotopes (Didukh et al., 1994; Khomiak et al., 2018), with the potential to use phytoindication tools developed for natural ecosystems in environmental assessments of such areas, due to the nonspecific nature of the response of living organism communities to environmental pollution (Yorkina et al., 2022; Maslikova, 2017).

The aim of our study is to assess the taxonomic diversity of plant communities developing on technosols in open-pit mining areas of the Nikopol manganese ore basin. Additionally, we aim to conduct an ecomorphic analysis to identify the ecological characteristics of processes occurring during land reclamation.

Material and methods

The experimental polygon for soil reclamation research was established in the late 1960s by Professors M.E. Bekarevich and M.T. Masyuk near Pokrov (Dnipro region, Ukraine) on the site of a manganese ore quarry. The climate of the study area is continental, with an average annual temperature of 11.14±0.30°C and annual precipitation ranging from 329 to 507 mm. The landscape features expansive, gently rolling plains, with loess and loess-like loams being the predominant geological surface rocks, extending several tens of meters in thickness. The area is located within the Central Pontic Grassland Zone (EuroVegMap). The field experiment, which has been ongoing for over 50 years, offers a unique opportunity to observe the transformation of rocks into fertile land. The research, conducted between 2008 and 2021, focused on sod-lithogenic soils, including loess-like loams, gray-green clays, red-brown clays, and pedozems (Yeterevska et al., 2008). From 1995 to 2003, perennial legume-grass agrophytocenosis grew at the site. In 2004, the process of overgrowing began (Demidov et al., 2013). Phytosociological relevés were made on 3×3 m (9 m²) plots. Although projective cover was assessed during fieldwork, this study focuses exclusively on species lists, and the projective cover data were not incorporated into the analysis. Between 105 and 160 relevés were made for each type of technosol, totaling 1,900 relevés. The vegetation cover was classified based on Raunkier′s life forms (Raunkiaer, 1934). Ecomorphic analysis according to O.L. Belgard (Belgard, 1950) was used as an effective tool for analyzing the properties of plant communities.

Research findings and discussion

Based on our findings and the data of M.T. Masyuk (Masyuk, 1971) and K.P. Maslikova (Maslikova, 2017), the vegetation cover of technosols in the Nikopol manganese ore basin was found to comprise 135 plant species. These were classified into two classes: Liliopsida (1 order, 1 family, 22 species) and Magnoliopsida (16 orders, 25 families, 113 species). The predominant families in plant communities on technosols were identified as Asteraceae, Poaceae, Brassicaceae, and Fabaceae, collectively accounting for 58.4% of the total species observed at the site (Fig. 1).

In the structure of vegetation cover based on Raunkiaer's life forms (Raunkiaer, 1934) and climamorphs as defined by O.L. Belgard (Belgard, 1950), hemicryptophytes were found to dominate (Fig. 2). Their placement of renewal buds on or near the soil surface determines their suitability for economic uses such as systematic haying and grazing. This adaptation helps them withstand overwintering and grazing pressure (Cain, 1950). Hemicryptophytes accounted for 45.26% (red-brown clay) to 52.38% (pedozem) of species richness. Terophytes, with an annual life cycle, formed 30.16–41.67%, reflecting community disturbance. Cryptophytes were represented by geophytes, characterized by renewal buds located in the surface soil layer. This placement provides excellent protection against freezing and trampling, making them highly resilient and durable in meadow ecosystems. The proportion of geophytes ranged from 7.37% (red-brown clay) to 14.29% (pedozem) based on species count. Phanerophytes (individual woody plants), nanophanerophytes, and chamaephytes appeared sporadically.

Among cenomorphs, stepants and ruderants were found to dominate, while pratants also played a significant role (Fig. 3). Stepants formed the core of the community, comprising 42.11–57.14% of the species. The lowest proportion of stepants was observed in red-brown clays, while the highest was found in pedozems. The proportion of ruderants ranged from 19.05% (red-brown clay) to 34.38% (loess-like loam). Meanwhile, pratants constituted 14.58% (loess-like loam) to 20.63% (pedozem), highlighting their importance in the community structure.

Sylvants, cultivars, and psammophytes occurred sporadically. Therefore, the plant communities formed on technosols were classified as steppe pseudomonocenoses with meadow and ruderal components. The hygromorph spectrum ranged from xerophytes to hygromesophytes (Fig. 4).

The community was predominantly composed of xeromesophytes and mesoxerophytes. Mesophyte proportions ranged from 30.16% (pedozem) to 38.54–38.55% (loess-like loam and grey-green clay), while xeromesophytes accounted for 38.54% (loess-like loam) to 46.03% (pedozem). Xerophytes constituted 2.11–3.17%, with no significant differences between technosol types. The highest mesophyte proportion was observed in pedozem (7.94%), followed by red-brown clay (5.26%), and lower proportions were recorded in loess-like loam and grey-green clay (3.13–3.61%). Hygromesophytes appeared sporadically.

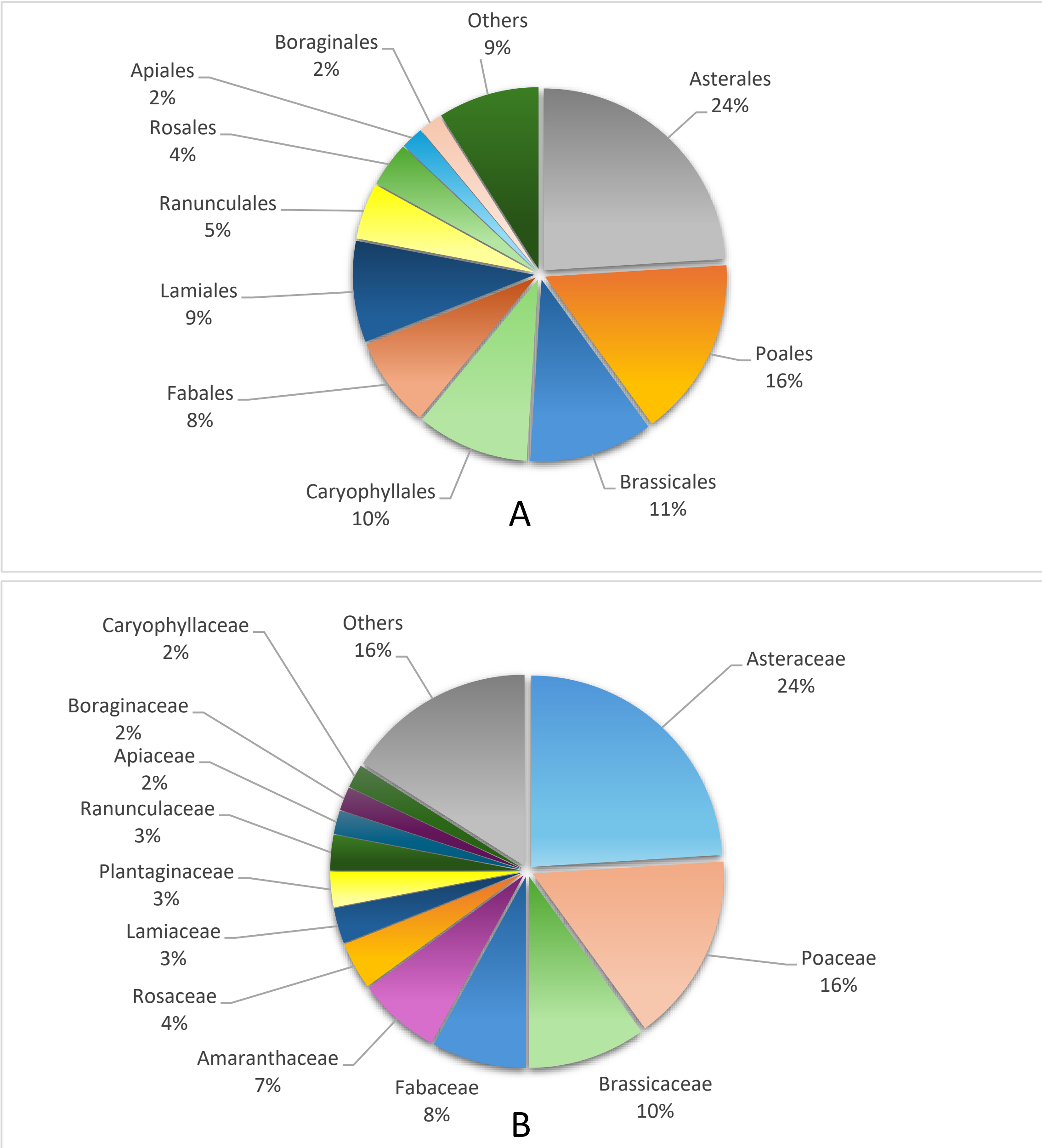

Figure 1. Taxonomic structure of the vegetation cover on sod-lithogenic soils and pedozems at the experimental site: (A) Distribution of orders; (B) Distribution of families.

Рисунок 1. Таксономічна структура рослинного покриву на дерново-літогенних ґрунтах та педоземах дослідної ділянки: (А) розподіл за відділами; (Б) розподіл за родинами.

The wide range of hygromorphs reflected significant variability in the soil moisture regime. The dominant hygromorphs were mesoxerophytes and xeromesophytes. This hygromorph spectrum indicated that the moisture regime of technosol edaphotopes was transitional between dry and fresh conditions. In terms of trophomorph structure, mesotrophs prevailed, accompanied by a notable proportion of megatrophs (Fig. 5).

The proportion of mesotrophs remained relatively consistent across all technosols (74.70–77.89%). The lowest proportion of megatrophs was found in red-brown clay and loess-like loam (16.84% and 16.67%, respectively), while the highest proportion was observed in pedozem (20.63%). The proportion of oligotrophs was lowest in pedozem (1.59%) and highest in loess-like loam (5.21%). Alkalitrophs appeared sporadically in pedozems. Therefore, the edaphotopes of these reclaimed ecosystems can be considered transitional, ranging from medium-rich to fertile in terms of their trophic regime.

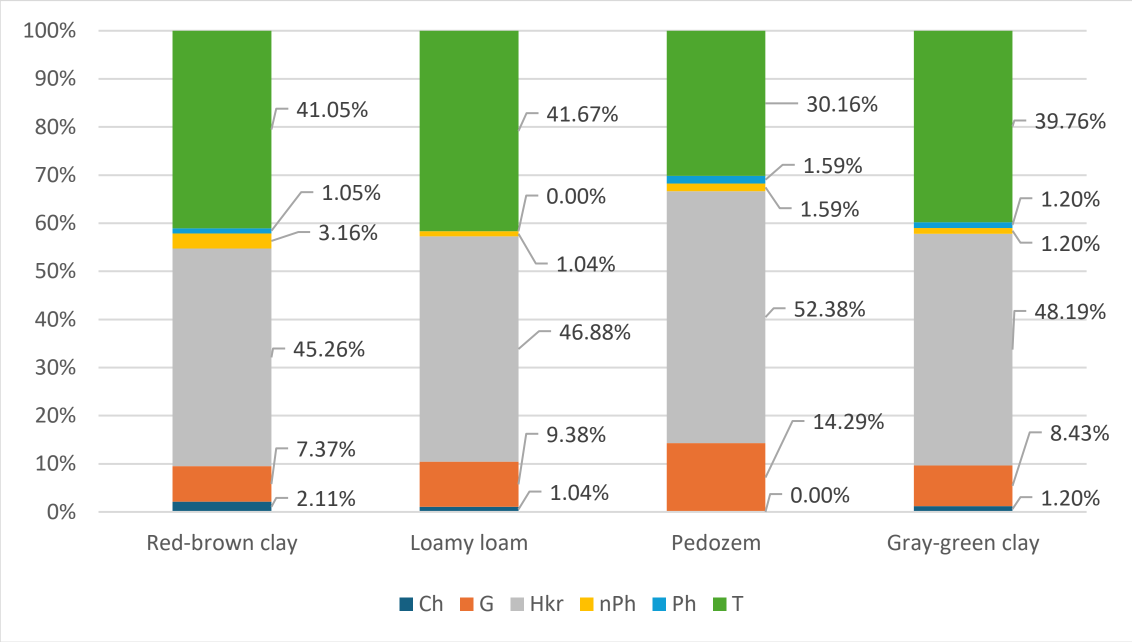

Figure 2. Distribution of life forms according to Raunkiaer's classification: Ph – Phanerophyte, nPh – Nanophanerophyte, Ch – Chamaephyte, HKr – Hemicryptophyte, T – Therophyte, and G – Geophyte. The vertical axis represents the proportion of each life form relative to the total number of species.

Рисунок 2. Розподіл життєвих форм відповідно до класифікації Раункієра: Ph – фанерофіти, nPh – нанофанерофіти, Ch – хамефіти, HKr – гемікриптофіти, T – терофіти, G – геофіти. На вертикальній осі показана частка кожної життєвої форми у відсотках відносно загальної кількості видів.

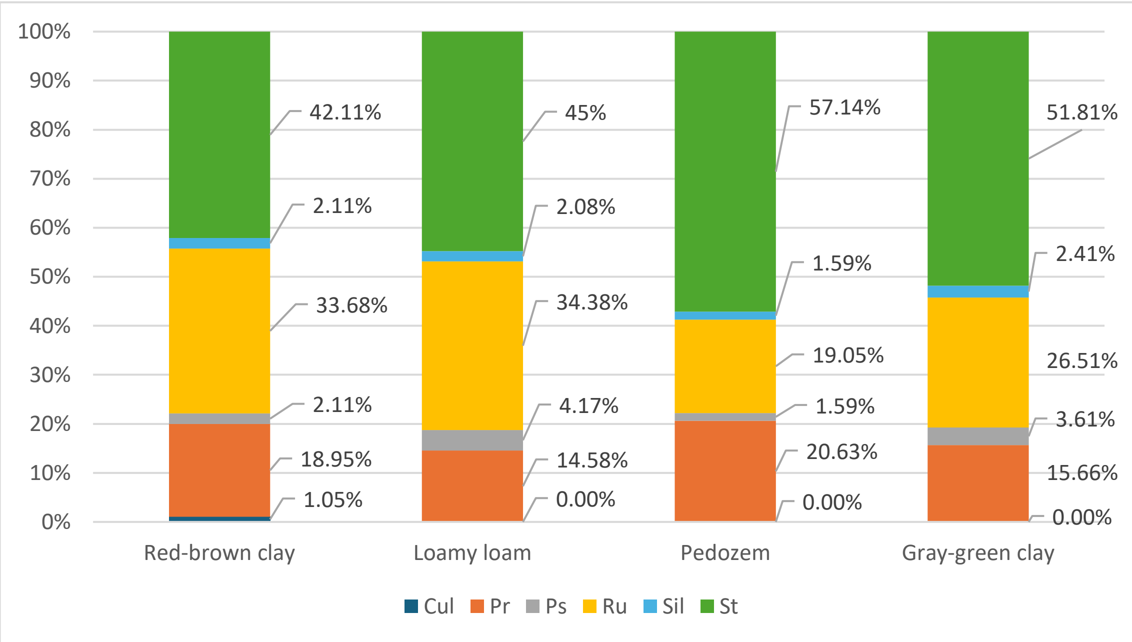

Figure 3. Structure of cenomorphs: Cul – culturants, Pr – pratants, Ps – psammophytes (psamants), Ru – ruderals, Sil – silvants, and St – stepants. The vertical axis represents the percentage of total species composition.

Рисунок 3. Структура ценоморф: Cul – культуранти, Pr – пратанти, Ps – псамофіти (псаманти), Ru – рудерали, Sil – сильванти, St – степанти. На вертикальній осі вказана частка групи відносно загальної кількості видів.

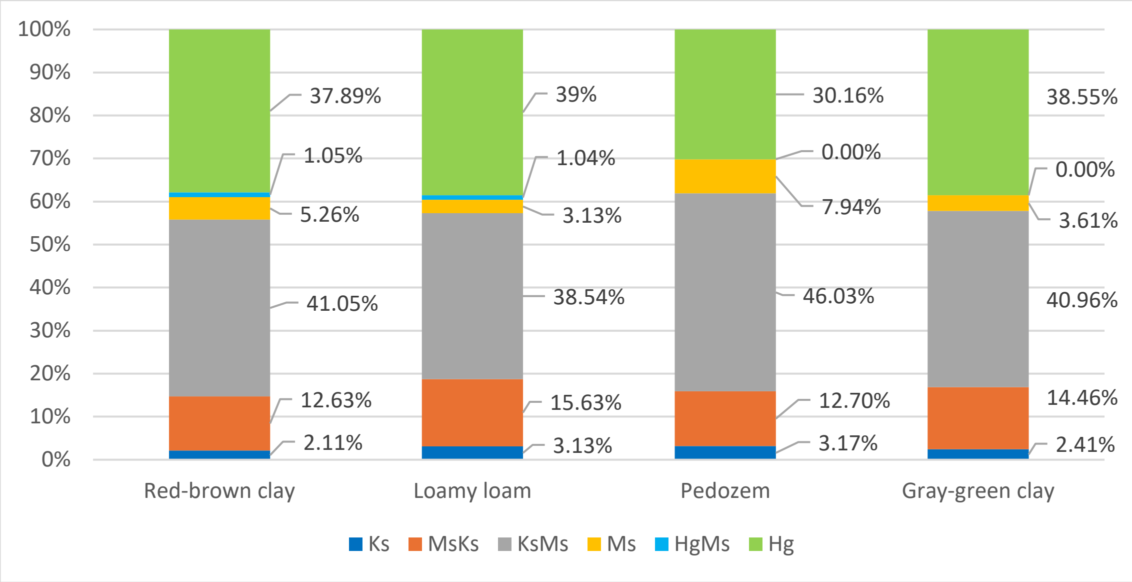

Figure 4. Structure of hygromorphs: Ks – xerophytes, MsKs – mesoxerophytes, KsMs – xeromesophytes, Ms – mesophytes, and HgMs – hygromesophytes. The vertical axis represents the percentage of total species composition.

Рисунок 4. Структура гідроморф: Ks – ксерофіти, MsKs – мезоксерофіти, KsMs – ксеромезофіти, Ms – мезофіти, HgMs – гігромезофіти. На вертикальній осі вказана частка групи відносно загальної кількості видів.

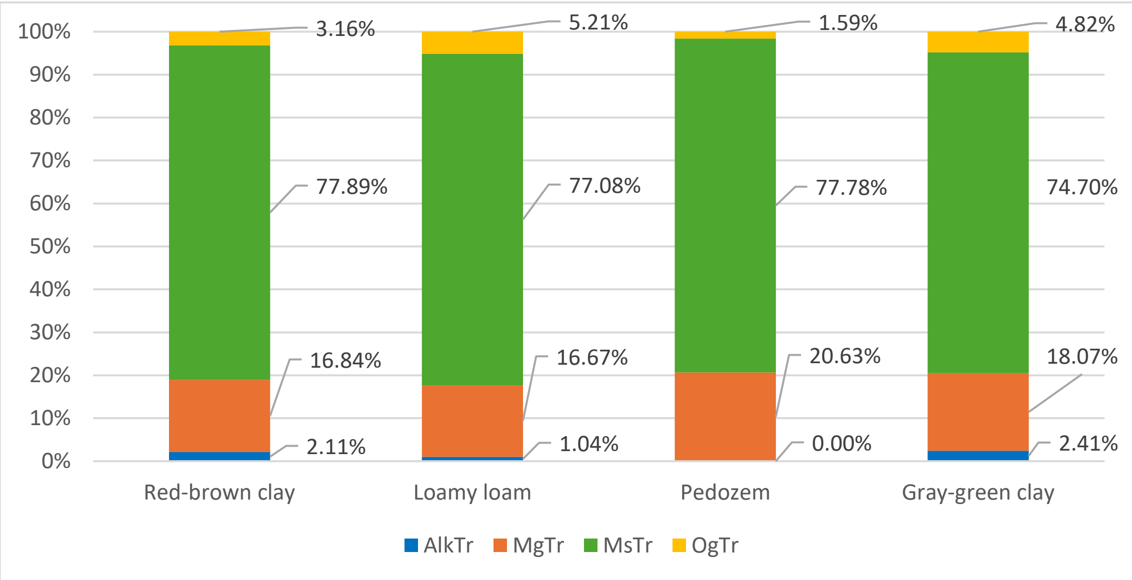

Figure 5. Structure of trophomorphs: AlkTr – alkalitrophs, MgTr – megatrophs, MsTr – mesotrophs, and OgTr – oligotrophs. The vertical axis represents the percentage of total species composition.

Рисунок 5. Структура трофоморф: AlkTr – алкалітрофи, MgTr – мегатрофи, MsTr – мезотрофи, OgTr – оліготрофи. На вертикальній осі вказана частка групи відносно загальної кількості видів.

The structure of heliomorphs was dominated by heliophytes (Fig. 6), which comprised 63.86% to 69.84% of the community in terms of species number. The most illuminated regime was observed in plant communities on pedozem. The proportion of sciogeophytes ranged from 30.16% in pedozem to 34.94% in gray-green clay. Heliosciophytes occurred sporadically.

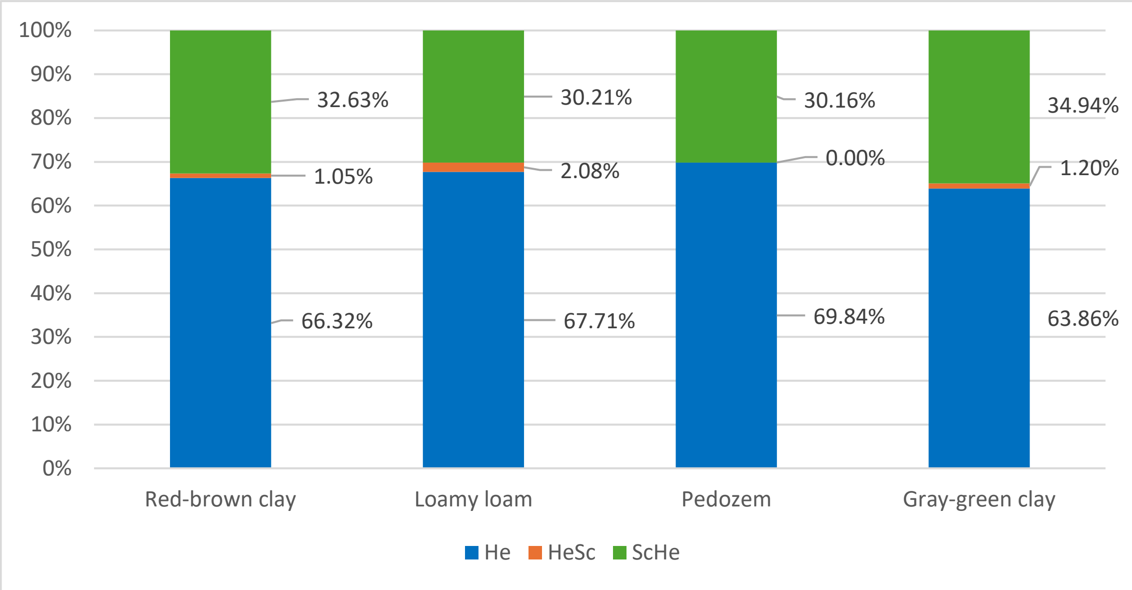

Figure 6. Structure of heliomorphs: HeSc – heliosciophytes; ScHe – scioheliophytes; He – areheliophytes. The vertical axis represents the percentage of total species composition.

Рисунок 6. Структура геліоморф: HeSc – геліосціофіти; ScHe – сціогеліофіти; He – геліофіти. На вертикальній осі вказана частка групи відносно загальної кількості видів.

Thus, the light regime of plant communities on technosols can be classified as light, with a tendency toward semi-light. These ecomorphs mainly reflect adaptations to the growth conditions, so they can be categorized as vegetative. Alongside vegetative ecomorphs, there are generative ecomorphs, which describe species' relationships to pollination and dispersal of diaspores. The pollen-choric structure reflects the pollination characteristics of the plant community.

The predominant type of pollination is entomophily, which involves insect pollination (Fig. 7). The proportion of entomophiles ranged from 66.27% to 77.78%. Anemophily, or wind pollination, is the second most common type. The lowest proportion of anemophiles was observed in plant communities on pedozem (22.22%), while the highest was found in the community on gray-green clay (31.33%).

During evolution, plants have developed diverse adaptations for dispersing their seeds and other generative units, a process termed diasporochory. Effective dispersal not only enhances a species' ability to colonize new habitats and stabilize a species' range but also guarantees their participation in phyto- and biocenoses (Levin et al., 2003; Nathan et al., 2008). Dispersal types, identified in our research site, are detailed in Figure 8, which illustrates the relative proportions within the community.

The plant community exhibited a wide range of diaspore dispersal mechanisms. The analysis revealed that dispersal mechanisms in the studied community occurs through two primary dispersal modes: ballistic dispersers, which eject seeds using explosive dehiscence as either the primary dispersal mechanism (Howe et al., 1982; Levin et al., 2003) or as a precursor to other dispersal methods (Swaine et al., 1979; Stamp et al., 1983; Hayashi et al., 2009); and anemochory, where seeds are dispersed by wind. Ballistic dispersers account for 52.38–57.89% of the total species richness, with the lowest proportion observed in plant communities on pedozem and the highest in those on red-brown clay. The proportion of anemochores ranged from 15.63% (loess-like loam) to 23.81% (pedozem). Autochores, which disperse their diaspores without external assistance, comprised 3.17–5.26% of the species. Closely related to autochores are barochores, in which seeds fall spontaneously under the influence of gravity. Barochory is common among cereals, particularly weeds. Barochores constituted 3.16–9.38% of the species within the community. Endozoochores and epizoochores rely on animals for seed transport. Pervolvents (tumbleweeds) represented a small but consistent component of the community.

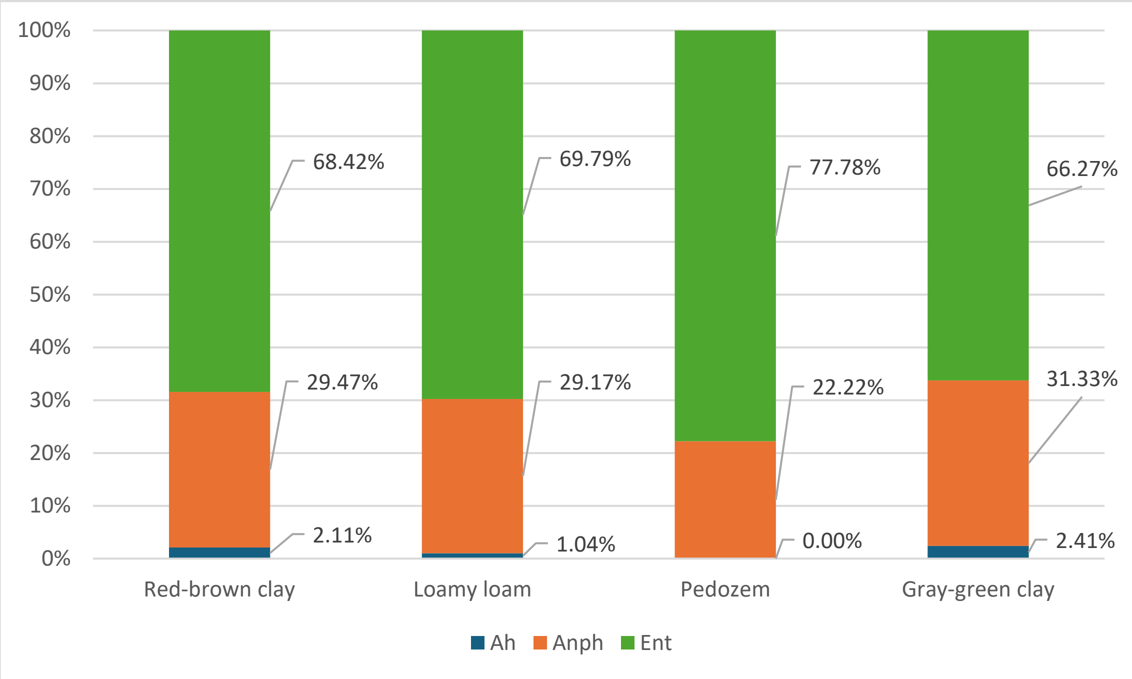

Figure 7. Structure of pollenochorus: Ah – autogamous plants; Anph – anemophiles; Ent – entomophiles. The vertical axis represents the percentage of total species composition.

Рисунок 7. Структура за типом запилення: Ah – автогамні рослини; Anph – анемофіли; Ent – ентомофіли. На вертикальній осі вказана частка групи відносно загальної кількості видів.

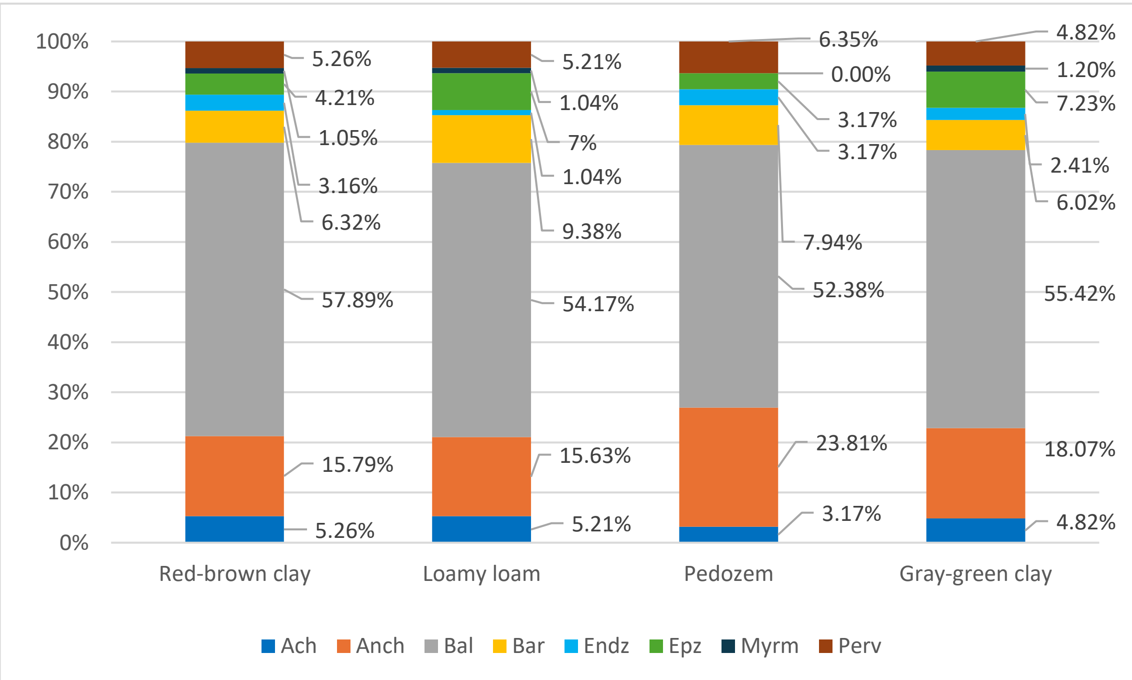

Figure 8. Structure of diasporochores: Ach – autochores; Anch – anemochores; Bal – ballistae; Bar – barochores; Endz – endozoochores; Epz – epizoochores; Perv – pervolvents. The vertical axis represents the percentage of total species composition.

Рисунок 8. Структура за типом розселення діаспор: Ach – автохори; Anch – анемохори; Bal – балісти; Bar – барохори; Endz – ендозоохори; Epz – епізоохори; Perv – первольвенти. На вертикальній осі вказана частка групи відносно загальної кількості видів.

After many years of agricultural use, the experimental reclamation sites were converted into fallow land, initiating the naturalization process of the vegetation. This process, ongoing for over 15 years, has led to the development of a diverse plant community on technosols, consisting of 135 vascular plant species, which account for 6.8% of the regional flora (Tarasov, 2012). The ranking of the most diverse plant families closely aligns with the sequence found in the regional flora: Asteraceae, Poaceae, Fabaceae, Brassicaceae, Caryophyllaceae, and Rosaceae. The flora of fallow lands of varying ages in the Apostoliv geobotanical area consists of 128 species, distributed across 102 genera and 24 families.

Natural succession processes indicate that soils can recover independently, ultimately becoming fully functional soils (Savosko et al., 2022). During vegetation succession, fallow lands pass through three distinct demutational stages: field weeds, rhizome cereals, and sod cereals, which naturally replace one another over time (Grime, 1977). The life form structure of plant communities on technosols is characteristic of the sod cereal stage (Itani et al., 2020). This stage is marked by the predominance of hemicryptophytes, with a moderate presence of terophytes. Terophytes, primarily ruderals, are often considered indicators of community instability (McIntyre et al., 1995).

In terms of species composition, all technosol types exhibit similar patterns. However, in communities on red-brown clays, the proportion of terophytes is slightly lower. Interestingly, when looking at projective coverage, the share of terophytes increases significantly, resembling earlier stages of succession dynamics (Alasmary et al., 2021).

The phenomenon can be attributed to the ongoing pedoturbation processes, where the swelling and shrinkage characteristic of young anthropogenic soils lead to the formation of deep cracks. These cracks allow soil from the upper layers to fall into them, increasing the dynamic nature of technogenic soils and expanding ecological space for early successional plants. The processes of hydraulic conductivity and water storage in cracked soils exhibit notable differences compared to those in intact soils (Fredlund et al., 2010). The technosol communities, in terms of their cenomorphic structure, align with the fallow lands in neighboring areas at the third demutational stage.

As fallow land ages, plant communities undergo xerophytization, but in technosols, this process is halted at the level of fresh conditions. This is significant for agricultural land reclamation, as the moisture availability in the edaphotopes is a key factor limiting agricultural productivity. Favorable conditions for crop cultivation are facilitated by the trophomorphic structure of the plant community, which reflects a trophic regime of technosol edaphotopes that approaches fertility.

The structure of the pollen chorus reflects the significant activity of phoric consortial relationships between plants and the animal population (Stefanovska et al., 2017). Overall, entomophiles make up 73% of the regional flora. In technosols on gray-green clays, the proportion of entomophiles is nearly identical to this figure, while in other types of technosols, it is significantly higher. The dominance of entomophiles further indicates the substantial potential of these plant communities as a foundation for beekeeping. The integration of reclaimed land vegetation into ecological processes is highlighted by the structure of diasporochores. The proportion of dominant ballistae is similar to that found in the regional flora (55–57%, according to Tarasov, 2012). However, the proportion of plants that rely on animals for diaspore dispersal is considerably higher than in the regional flora.

Conclusion

The vegetation cover of technosols was represented by 135 species of vascular plants. The plant communities were predominantly composed of species from the families Asteraceae, Poaceae, Fabaceae, Brassicaceae, and Rosaceae in terms of species richness. Taxonomically, the flora of technosols closely mirrored the regional flora. In terms of climamorphs, hemicryptophytes dominated, followed by terophytes. This structure is a characteristic of the turf grass succession stage. Among cenomorphs, steppe and ruderal species were the most prevalent. The plant communities on technosols were classified as steppe pseudomonocenoses, which included meadow and ruderal components.

The humidity regime of technosol edaphotopes was identified as a transitional, lying between dry and fresh conditions, while the trophic regime of these artificially created ecosystems ranged from medium-rich to fertile. These combined trophic and humidity conditions are favorable for crop cultivation. The vegetation cover on technosols was highly integrated into consortial relationships with other components of anthropogenic ecosystems. Notably, there was significant development of endozoochores, epizoochores, and pervolvents within these plant communities.

Alasmary Z., Hettiarachchi G.M., Roozeboom K.L., Davis L.C., Erickson L.E., Pidlisnyuk V., Stefanovska T., Trögl J. Phytostabilization of a contaminated military site using Miscanthus and soil amendments. *Journal of Environmental Quality*. 2021. Vol. 50. DOI: https://doi.org/10.1002/jeq2.20268

Antwi E.K., Boakye-Danquah J., Asabere S.B., Takeuchi K, Wiegleb G. Land cover transformation in two post-mining landscapes subjected to different ages of reclamation since dumping of spoils. SpringerPlus. 2014. Vol. 3. Article 702. DOI: https://doi.org/10.1186/2193-1801-3-702

Arora B., Mohanty B.P., McGuire J.T., Cozzarelli I.M. Temporal dynamics of biogeochemical processes at the Norman landfill site. *Water Resources Research*. 2013. Vol. 49, № 10. P. 6909 – 6926. DOI: https://doi.org/10.1002/wrcr.20484

Bao N., Ye B., Bai Z. Monitoring land degradation and reclamation change from ATB open-pit coal mine during 1976 – 2009. *International Conference on Mechanic Automation and Control Engineering*. 2010. P. 1480–1485.

Belgard A.L. Forest vegetation of South-Eeast part of the USSR. Kiev: Kiev State University (in Russian). 1950. P. 263.

Bradshaw A. The use of natural processes in reclamation – advantages and difficulties. *Landscape and Urban Planning*. 2000. Vol. 51. Issues 2–4. P. 89 – 100. ISSN 0169-2046. DOI: https://doi.org/10.1016/S0169-2046(00)00099-2

Cain S.A. Life-forms and phytoclimate. *The Botanical Review*. 1950. Vol. 16. P. 1–32. DOI: https://doi.org/10.1007/BF02879783

Chitade A.Z., Katyar S.K. Impact analysis of open cast coal mines on land use/land cover using remote sensing and GIS technique: A case study. *International Journal of Engineering Science and Technology*. 2010. Vol. 2, № 12. P. 7171–7176.

Demidov A.A., Kobets A.S., Grytsan Yu.I., Zhukov A.V. Spatial Agroecology and Land Recultivation. Dnipro: Svidler A. L. Publishing House, 2013. P. 560. ISBN: 978-617-627-055-3. DOI: 10.13140/RG.2.1.5175.5040

Denysyk H., Mizina S. Regional reclamation landscape technical systems: current status and rational use. *Journal of Geology, Geography and Geoecology*. 2021. Vol. 30, № 3. P. 421–428. DOI: https://doi.org/10.15421/112138

Didukh Ya.P., Plyuta P.H. 1994. The phytoindication of ecological factors. Ed. K.M. Sytnyk. Kyiv : Naukova Dumka, 280 pp.

Domnich V.I., Domnich A.V., Zhukov O.V. Phytoindication approach to assessing factors determining the habitat preferences of red deer (Cervus elaphus). *Biosystems Diversity*. 2021. Vol. 29, № 3. P. 195–206. DOI: https://doi.org/10.15421/012124

Drummond M.A., Stier M.P., Auch R.F., Taylor J.L., Griffith G.E., Riegle J.L., Hester D.J., Soulard C.E., McBeth J.L. Assessing landscape change and processes of recurrence, replacement, and recovery in the Southeastern Coastal Plains, USA. *Environmental Management*. 2015. Vol. 56, № 5. P. 1252–1271. DOI: https://doi.org/10.1007/s00267-015-0574-1

Ellis E.C. Anthropogenic transformation of the terrestrial biosphere. *Philosophical Transactions of the Royal Society* A: Mathematical, Physical and Engineering Sciences. 2011. Vol. 369, № 1938. P. 1010–1035. DOI: https://doi.org/10.1098/rsta.2010.0331

Fredlund DG, Houston SL, Nguyen Q, Fredlund MD. Moisture Movement Through Cracked Clay Soil Profiles. *Geotechnical and Geological Engineering*. 2010. Vol. 28. P. 865–888. DOI: 10.1007/s10706-010-9349-x

Grime J.P. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist*. 1977. Vol. 111, № 982. P. 1169–1194.

Gruss I., Stefanovska T., Twardowski J., Pidlisnyuk V., Shapoval P. The ecological risk assessment of soil contamination with Ti and Fe at military sites in Ukraine: Avoidance and reproduction tests with Folsomia Candida. *Reviews on Environmental Health*. 2019. Vol. 34, № 3. DOI: https://doi.org/10.1515/reveh-2018-0067

Hayashi M., Feilich K. L., Ellerby D. J., The mechanics of explosive seed dispersal in orange jewelweed (Impatiens capensis), *Journal of Experimental Botany*. 2009. Vol. 60. Issue 7. P. 2045–2053. DOI: https://doi.org/10.1093/jxb/erp070

He D., Ruan H. Long term effect of land reclamation from lake on chemical composition of soil organic matter and its mineralization. *PLOS ONE*. 2014. Vol. 9, № 6. Article e99251. DOI: https://doi.org/10.1371/journal.pone.0099251

Howe HF, Smallwood J. Ecology of seed dispersal. *Annual Review of Ecology and Systematics*. 1982. Vol. 13. P. 201–228.

Izakovičová Z., Petrovič F., Pauditšová E. The impacts of urbanisation on landscape and environment: The case of Slovakia. *Sustainability*. 2022. Vol. 14, № 1. Article 60. DOI: https://doi.org/10.3390/su14010060

Joimel S., Grard B., Chenu C., Cheval P., Mondy S., Lelièvre M., Auclerc A., Vieublé Gonod L. One green roof type, one Technosol, one ecological community. *Ecological Engineering*. 2022. Vol. 175. Article 106475. DOI: https://doi.org/10.1016/j.ecoleng.2021.106475

Just Th. Review of The Life Forms of Plants and Statistical Plant Geography, by C. Raunkiaer. *The American Midland Naturalist*, 1934. Vol. 15, № 6. P. 786–787. DOI: 10.2307/2419902

Kharytonov M.M., Stankevich S.A., Titarenko O.V., Doležalová Weisssmannová H., Klimkina I.I., Frolova L.A. Geostatistical and geospatial assessment of soil pollution with heavy metals in Pavlograd City (Ukraine). *Ecological Questions*. 2020. Vol. 31, № 2. DOI: https://doi.org/10.12775/EQ.2020.013

Kharytonov M., Klimkina I., Martynova N., Rula, I., Gispert M., Pardini G. Estimation of the biochar effect on annual energy crops grown in post-mining lands. *Ecological Engineering & Environmental Technology*. 2021. Vol. 22, № 2. P. 15–26. DOI: https://doi.org/10.12912/27197050/133257

Khomiak, I.V., Demchuk, N.S., Vasylenko, O.M., Phytoindication of anthropogenic transformation of ecosystems on the example of the Ukrainian Polissia. *Ecological Sciences*. 2018. Vol. 3(22), P. 113–118.

Kunakh O.N., Kramarenko S.S., Zhukov A.V., Kramarenko A.S., Yorkina N.V. Fitting competing models and evaluation of model parameters of the abundance distribution of the land snail Vallonia pulchella (Pulmonata, Valloniidae). *Regulatory Mechanisms in Biosystems*. 2018. Vol. 9, № 2. DOI: https://doi.org/10.15421/021829

Kunakh O.M., Lisovets O.I., Yorkina N.V., Zhukova Y.O. Phytoindication assessment of the effect of reconstruction on the light regime of an urban park. *Biosystems Diversity*. 2021. Vol. 29, № 3. DOI: https://doi.org/10.15421/012135

Kuter N. Reclamation of degraded landscapes due to opencast mining. Advances in Landscape Architecture. InTech, 2013. DOI: 10.5772/55796

Levin S.A., Muller-Landau H.C., Nathan R., Chave J. The ecology and evolution of seed dispersal: A theoretical perspective. *Annual Review of Ecology, Evolution, and Systematics*. 2003. № 34. P. 575–604. DOI: 10.1146/annurev.ecolsys.34.011802.132428

Maslikova K. Vegetation Ecological Structure of Nikopol Manganese Ore Basin Replantosems. *Bulletin of Dnipropetrovsk State Agrarian and Economic University*. 2017. № 4. P. 77–88.

Maslikova E.P. Phytoindication spatio-temporal structures tehnozemov and endogenous mechanisms of sustainable functioning of anthropogenic soil-like bodies. *Agrology*. 2018. Vol. 1, № 3. P. 273–280. DOI: 10.32819/2617-6106.2018.13006

Maslikova K.P. Ecomorphic structure of the soil macrofauna communities of technosols of the Nikopol manganese ore basin. *Biosystems Diversity*. 2018. Vol. 26, № 2. P. 85–91. DOI: 10.15421/011813

McIntyre S., Lavorel S., Tremont R.M. Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology*. 1995. Vol. 83. P. 31–44.

Masyuk N.T. Natural Vegetation of Manganese Opencast Mines and Its Ecological and Biological Characteristics. Dnipropetrovsk : Promin, 1971.

Nathan R., Schurr F.M., Spiedel O., Steinitz O., Trakhtenbrot A., Tsoar A. Mechanisms of long-distance seed dispersal. *Trends in Ecology & Evolution*. 2008. Vol. 23. P. 638–647. DOI: 10.1016/j.tree.2008.08.003

Nazarenko N.N. Coenomorphs as phytometers of biotopes. *Biosystems Diversity*. 2016. Vol. 24, № 1. P. 8–14. DOI: 10.15421/011602

Nebeská D., Pidlisnyuk V., Stefanovska T., Trögl J., Shapoval P., Popelka J., Černý J., Medkow A., Kvak V., Malinská H. Impact of plant growth regulators and soil properties on Miscanthus × giganteus biomass parameters and uptake of metals in military soils. *Reviews on Environmental Health*, 2019. Vol. 34, № 3. P. 283–291. DOI: 10.1515/reveh-2018-0088

Nurzhanova A., Pidlisnyuk V., Abit K., Nurzhanov C., Kenessov B., Stefanovska T., Erickson L.

Comparative assessment of using Miscanthus × giganteus for remediation of soils contaminated by heavy metals: a case of military and mining sites. *Environmental Science and Pollution Research*, 2019. Vol. 26. P. 13320–13333. DOI: 10.1007/s11356-019-04707-z

Paoletti M.G. Using bioindicators based on biodiversity to assess landscape sustainability. *Agriculture, Ecosystems & Environment*, 1999. Vol. 74, № 1–3. P. 1–18. DOI: 10.1016/S0167-8809(99)00027-4

Pakhomov O.Y., Kunakh O.M., Babchenko A.V., Fedushko M.P., Demchuk N.I., Bezuhla L.S., Tkachenko O.S. Temperature effect on the temporal dynamic of terrestrial invertebrates in technosols formed after reclamation at a post-mining site in Ukrainian steppe drylands. *Biosystems Diversity*, 2019. Vol. 27, № 4. P. 322–328. DOI: 10.15421/011942

Pidlisnyuk V., Shapoval P., Zgorelec Ž. Stefanovska T., Zhukov O. Multiyear phytoremediation and dynamic of foliar metal(loid)s concentration during application of Miscanthus × giganteus Greef et Deu to polluted soil from Bakar, Croatia. *Environ. Sci Pollut. Res*. 2020. Vol. 27. P. 31446–31457. DOI: 10.1007/s11356-020-09344-5

Pidlisnyuk V., Stefanovska T., Zhukov O., Medkow A., Shapoval P., Stadnik V., Sozanskyi M. Impact of Plant Growth Regulators to Development of the Second Generation Energy Crop Miscanthus × giganteus Produced Two Years in Marginal Post-Military Soil. *Applied Sciences*, 2022. Vol. 12, № 2. P. 881. DOI: 10.3390/app12020881

Sattler T., Borcard D., Arlettaz R., Bontadina F., Legendre P., Obrist M. Spider, bee, and bird communities in cities are shaped by environmental control and high stochasticity. *Ecology*. 2010. Vol. 91, № 10. P. 3343–3353. DOI: 10.1890/09-1810.

Savosko V.M., Bielyk Y.V., Lykholat Y.V. & Heilmeier H. (2022). Assesment of heavy metals concentration in initial soils of post-mining landscapes in Kryvyi Rih District (Ukraine). *Ekológia* (Bratislava). Vol. 41(3). P. 201–211. DOI: 10.2478/eko-2022-0020

Stamp N.E., Lucas J.R. Ecological correlates of explosive seed dispersal. *Oecologia*. 1983. 59, P. 272–278.

Stefanovska T., Pidlisnyuk V., Lewis E., Gorbatenko A. Herbivorous insects diversity at Miscanthus × giganteus in Ukraine. *Agriculture* (*Poľnohospodárstvo*). 2017. Vol. 63, № 1. P. 23–32. DOI: 10.1515/agri-2017-0003

Stefanovska T., Skwiercz A., Zouhar M. Pidlisnyuk V., Zhukov O. Plant-feeding nematodes associated with *Miscanthus × giganteus* and their use as potential indicators of the plantations state. *Int. J. Environ. Sci Technol*. 2021. Vol. 18. P. 57–72. DOI: 10.1007/s13762-020-02865-z

Stefanovska T., Skwiercz A., Pidlisnyuk V., Zhukov O., Kozacki D., Mamirova A., Newton R.A., Ust′ak S. The Short-Term Effects of Amendments on Nematode Communities and Diversity Patterns under the Cultivation of Miscanthus × giganteus on Marginal *Land. Agronomy*. 2022. Vol. 12, № 9. P. 2063. DOI: 10.3390/agronomy12092063

Swaine M.D., Dakubu T., Beer T. On the theory of explosively dispersed seeds: a correction. *New Phytologist*. 1979. 82. P. 777–781. DOI:10.1111/j.1469-8137.1977.tb02173.x

Tarasov V.V. Flora Dnipropetrovskoji ta Zaporizkoji oblastej. Dnepropetrovsk : Lira, 2012. (in Ukrainian) 296 p.

Trepanier K.E., Pinno B.D., Errington R.C. Dominant drivers of plant community assembly vary by soil type and time in reclaimed forests. *Plant Ecol*. 2021. № 222. P. 159–171. DOI: 10.1007/s11258-020-01096-z

Valdes Y., Viaene N., Moens M. Effects of yellow mustard amendments on the soil nematode community in a potato field with focus on Globodera rostochiensis. *Appl. Soil Ecol*. 2012. Vol. 59. P. 39–47.

Valentín-Vargas A., Neilson J.W., Root R.A., Chorover J., Maier R.M. Treatment impacts on temporal microbial community dynamics during phytostabilization of acid-generating mine tailings in semiarid regions. *Sci. Total Environ*. 2018. Vol. 618. P. 357–368. DOI: 10.1016/j.scitotenv.2017.11.010

Yeterevska L.V., Momot G.F., Lehtsiyer L.V. Rekultyvovani grunty: pidkhody do klasyfikatsii ta systematyky [Reclaimed soils, approaches to classification and taxonomy]. *Soil Science*. 2008. Vol. 9, № 3–4. P. 147–150. (in Ukrainian).

Yorkina N., Goncharenko I., Lisovets O., Zhukov O. Assessment of Naturalness: The Response of Social Behavior Types of Plants to Anthropogenic Impact. *Ekológia* (Bratislava). 2022. Vol. 41. P. 135–146. DOI: 10.2478/eko-2022-0014

Yorkina N., Maslikova K., Kunah O., Zhukov O. Analysis of the spatial organization of Vallonia pulchella (Muller, 1774) ecological niche in technosols (Nikopol manganese ore basin, Ukraine). *Ecologica Montenegrina*. 2018. Vol. 17. P. 29–45. DOI: 10.37828/em.2018.17.5

Yorkina N., Zhukov O., Chromysheva O. Potential Possibilities of Soil Mesofauna Usage for Biodiagnostics of Soil Contamination by Heavy Metals. *Ekológia* (Bratislava). 2019. Vol. 38, № 1. P. 1–10. DOI: 10.2478/eko-2019-0001

Zhukov A., Gadorozhnaya G. Spatial Heterogeneity of Mechanical Impedance of Atypical Chernozem: The Ecological Approach. *Ekológia* (Bratislava). 2016. Vol. 35, № 3. P. 263–278. DOI: 10.1515/eko-2016-0021

Zhukov O.V., Zadorozhna G.O., Maslikova K.P., Andrusevych K.V., & Lyadskaya I.V. Tehnosols Ecology: monograph. Zhurfond, Dnipro (in Ukrainian). 2017. 442 p.

Zhukov O., Kovalenko D., Kramarenko S., Kramarenko A. Analysis of the spatial distribution of the ecological niche of the land snail Brephulopsis cylindrica (Stylommatophora, Enidae) in technosols. *Biosystems Diversity*. 2019. Vol. 27. P. 62–68. DOI: 10.15421/011910

Zymaroieva A., Zhukov O., Fedoniuk T., Pinkina T., Hurelia V. The Relationship Between Landscape Diversity and Crops Productivity: Landscape Scale Study. *Journal of Landscape Ecology*. 2021. Vol. 14, № 1. P. 39–58. https://doi.org/10.2478/jlecol-2021-0003

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