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Satbayev University

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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ENVIRONMENTAL SAFETY OF PHYTOGENIC FIELDS FORMATION ON COAL MINES TAILINGS

Abstract. Objective of the study is to research peculiarities of phytogenic fields formation of natural and artificial plantations of shrub and ruderal vegetation on coal mining waste heaps within the Novovolynsk mining area (Ukraine). The biometric analysis of the growth of artificial plantations on tailings has been carried out applying forest inventory methodology, which involves laying temporary experimental areas, measuring the diameter of tree species at a height of 1.3 m, the total height of trees and the parameters of crowns. Variation was applied to study the spatial structure of vegetation on reclaimed and damped waste heaps. The models of artificial phytocenoses and ameliorants on waste heaps of coal mines, which are formed during forest reclamation, have been described. The paper presents an analysis of forest inventory characteristics of the crops phytocenosis on waste heaps. The spatial structure of phytogenic fields basing on variation of the most common species in natural and artificial plantations on waste heaps has been established. This allows us to select an assortment of species to conduct effective vegetative reclamation on the surface of tailings. The article presents result of studies on the formation of phytogenic fields on waste heaps of coal mines, which presuppose formation of aggregations. It has been proved that formation of phytogenic fields is inextricably connected with vegetative reclamation. The conducted research of the origin and distribution of phytogenic fields makes it possible to assess the degree of suitability of tailings for afforestation, regardless of the country in which they are formed. Research of phytogenic fields on tailings and waste heaps of coal mines will improve bioindication research methodology for studying forest crops on their surface and suggest innovative methods of handling. In particular, it is possible to raise the level of environmental safety and aesthetics of the devastated territories, and to reduce cost of vegetative reclamation.

Keywords: environmental safety, phytogenic field, coal mine, tailing, phytocenosis, forest crops, reclamation.

Introduction. The rehabilitation of ecosystems cannot be imagined without plant communities. Vegetation communities on the devastated landscapes are individualized in order to characterize them according to ectopic characteristics (foot, slopes, terraces, plateau) and development stages. Taking into account that ecological successions are evaluated by the material, energy and information components, they should be considered as a phytogenic field. The development of the doctrine of the phytogenic field began in the 1960s and is closely interwoven with vegetative reclamation. The phytogenic field consists of two separate parts: internal and external. The external part of the phytogenic field is limited to the space where the living or dead parts of the plant are physically present. The boundaries of the external part of the phytogenic field are also determined by the extent of the penetration of the horizontal roots, in the presence of leaf litter. The size of the inner part of the phytogenic field is determined by the diameter of the aboveground or underground spheres, that is, the space occupied by the main body of the root system of the plant or the diameter of the crown of the tree or shrub. The allelopathy which determines the chemical interaction between plants, can play a significant role in phytogenic fields of plants along with light, trophic, temperature, humidity regimes. Devastated landscapes are present in many countries around the world where industry is aimed at extraction of minerals. Among them are Germany, the USA, China,

Russia, Mexico, South Africa, Australia, India and Ukraine. Although in rare cases, when during mineral deposits development the technology of goaf backfill with rock dump waste utilization is used the dumping is reduced [1, 2]. It should be noted that in Ukraine a significant amount of coal mining waste is accumulated annually due to the development of thin coal seams with a thickness of 0.7-1.2 m, which makes it necessary to coal-cutting with stone in stopping faces and carry out continuous mining of coal and rock during mining and produce coal enrichment processes [3, 4]. On the spoil heaps, like on the devastated landscapes, specific edaphic and climatic conditions for the development of vegetation were established [5]. The problem of vegetative reclamation of devastated landscapes is actively explored by many scientists. Some important issues of vegetative reclamation of devastated landscapes are not sufficiently explored. Among them are the investigation of the phytocoenotic structure of vegetation of various tailings types and the influence of environmental factors on the development of vegetation cover. The most pressing is the development of the ecological safety of phytogenic fields in devastated landscapes, where the plants are under significant man-made pressure caused by anthropogenic human activities [6]. The investigation of the features of phytogenic fields interference on the tailings is important for developing a reliable forecast of species coexistence and the formation of the continuum.

Purpose, tasks and methods of research. The aim of the research is to investigate the features of ecological safety of the phytogenic fields formation of artificial and natural plantations of tree-and-shrub and ruderal vegetation on coal mine tailings within the Novovolynsk mining area (Ukraine). According to the aim, the following tasks were foreseen: to establish the ecological safety of forest plantations by describing models of artificial phytocoenoses-ameliorants on waste heaps of coal mines, which are formed during forest remediation; to describe of the ecological succession of tailings; to establish the spatial structure of phytogenic fields on the basis of dispersion of the most common types in natural and artificial plantings of waste heaps.

A lot of scientific works were devoted to the concept of the phytogenic fields formation in different environmental conditions. We'll concentrate on the analysis of scientific works, which significantly influenced the development of the theory of phytogenic field of individuals and phytocoenoses in conditions of devastated territories. The scientific work [7] is devoted to the development of the phytogenic field for the standpoint of a single-growing plant. The illumination and ultraviolet regime of the inner part of the phytogenic field is investigated. It is established that the regime of ultraviolet radiation correlates with the illumination regime in the visible range, which is determined by morphostructural features of plants. Significant contribution to the theory of the phytogenic field formation in different conditions of inhabitation places is made in the work [8]. The main types of phytogenic fields of the plants of different biomorphs and changes in the process of ontogenesis are described. According to the presented theory, the phytogenic field is a set of phytogenic fields of cenopopulations of certain species, which form phytocenosis. Such theory is true, since the phytogenic field of a single plant does not have a significant effect on the development of phytocenotic cover. The disadvantage of this work is the lack of a description of the phytogenic fields in the devastated territories, because in conditions of landscape-transforming factors, the dynamics of development and the resistance of phytocoenoses are different from the conditions of the meadows. In the research paper [9] the author concludes that there are three concentration zones of phytogenic fields in the tailings that depend on the distance from tree stem, that is undertree, top, external. Identification characteristic of the undertree zone of phytogenic field is the forest litter with 100 % projective cover. Top zone takes into account moss cover and has a low growth rate. The external zone is characterized by herb species. The external zone has a high coefficient of similarity to the background values. The numerous studies presented are valuable in terms of influence of climatological and edaphic conditions on the formation and development of the phytogenic field. However, these studies describe only one species – the Scotch pine. This is not enough to evaluate the transformative function of vegetative cover on mine tailings. In [10] it was found that specific microbial functional communities on rock dumps are associated with groups of plants, and not with individual species. This relationship proves that it is the phytogenic fields of the communities that create the conditions for the further development of successions. It has been proved that the development of phytogenic fields and the characteristics of soil infiltration have a correlation (positive correlation) with age. This suggests that the recultivation approach to ecosystem rehabilitation is effective. However, complete recovery is a long process [11].

Applied investigations of improvement of efficiency of coal mines ecological restoration by phytomelioration methods are reflected in [12]. An experiment and field studies were conducted to

investigate the effect of micromycetes on plant growth performance. This approach has led to the development of environmentally safe technologies for soil restoration through phytoremediation. The ways of remediation works are closely related to the planning of land use [13]. The tailings body may remain in its original state or undergo minimal changes of its surface. Another possibility is partial dispose of the waste to the dump, and further aligning according to the needs. The best option is a complete dismantling of the dump and remediation of the area. According to the experimental results of the research [14] vegetative reclamation of the tailings is an effective way to reduce runoff and soil erosion and it is a key element in ecosystems restoring in environmentally hazardous regions. In the research paper [15] changes in the species diversity of plants, physical and chemical properties of soils on tailings of all ages have been investigated. It has been proved that species diversity, as well as the coverage and biomass of herb species, has increased significantly over time. Phytogenic fields of populations have been generated. However, for shrubs, the initial increase in species diversity was observed during the first 10 years, after which there was a gradual decrease. In general, the vegetation cover on the mines tailings is typical of the tops. On the slopes of a significant gradient, the overgrown is much smaller. The revegetation cover on the aged tailings is much more stable than freshly placed ones [16]. The research [17] reflected the influence of vegetative reclamation on the hydrological processes of the rock refuse. It was concluded that the infiltration rate and hydraulic conductivity were significantly higher in the afforestation area. In the research paper [18] the use of local species for the mechanical stability of landfills on the surface of an iron ore dump for the long-term environmental protection is investigated. It was established that the mechanical stability of the dump significantly improved after vegetative reclamation of the slopes. The positive role of soil algae in the development of higher plants on the rock refuses should be noted. The research [19] has shown that a large number of soil algae in dumps of copper mines increases due to the decrease of the heavy metals content and improvement of nutritional conditions. The growth of soil algae has created good conditions for the higher plants dispersal and growth. The appearance of moss and vascular plants inhibited the development of soil algae in dumps of copper mines.

The peculiarities of the phytogenic field formation the on the rock dumps of coal mines have not yet been fully studied and are the first thing that require the vegetative reclamation processes to be set and, as a consequence, the proper conditions to be established for the phytocenoses development. It should be noted that the investigations of the shrubs phytogenic fields are not numerous. This situation is caused by the fact that, in contrast to the well-known transformative function of trees, shrubs in forest populations have a subordinate role of underwood with a small cenotic role.

Results and their discussion. Since some mines of the Novovolynsk mining area ("Mines No 2, 3, 4, 6, 7, 8 Novovolinsk") were abandoned, the process of recultivation of damping heaps was not carried out properly. It is caused by insufficient financing of reclamation, obsolete technical equipment and the lack of effective methods for plantations creating in consonance with the region's specificity. In the process of artificial vegetation, which was carried out on the heaps of "Mine No. 2, 3, 8 Novovolynsk", the dominant species was *Robinia pseudoacacia* L., which is present on all the waste heaps. This species grows mainly on the slopes. During the investigation other species were found - *Betula pendula* Roth., *Salix caprea* L., *Quercus robur* L. According to the results of field studies, it has been found that representatives of following families are present on reclaimed heaps: *Asteraceae, Menyanthaceae, Scrophulariaceae, Urticaceae, Rosaceae, Compositae, Fabaceae, Lamiaceae, Caryophyllaceae, Brassicaceae Burnett (Cruciferae Juss.), Poaceae, Plantaginaceae, Violaceae, Umbelliferae, Malvales, Apiacaeae, Geraniaceae, Betulaceae, Fagaceae, Salicaceae, Rubiaceae*. Characteristic of heaps with artificial vegetation is that green plantations cover the slopes and only partially the top. At the same time, on the northern slope of the heap colonization by vegetation is more intense due to the higher humidity of the substrate. On the eastern slope there are the typical for Small Polesye forest plants *Calamagrostis epigeios (L.) Roth., Galium verum L., Fragaria vesca L.* On the reclaimed tailings a plantation was created by: *Sorbus aucuparia L., Ligustrum vulgare L., Sambucus nigra L.* The wood-shrub mixing type (single-shrub version): *Robinia pseudoacacia L.* (main species - M) and *Ligustrum vulgare L.* (shrub - S) was used according to the following scheme: M-S-M-S-M-S-M-S-…; S-M-S-M-S-M-S-M-…

The distance between rows was 2.5 m, in the series - 2.0 m. The formation of phytogenic medium in the intermediate row was provided. These plantations were created on all slopes and surfaces of the reclaimed waste heap "Mine No.2 Novovolinska". The highest development of the plantation was on the

northern slope, and the lowest - on the western side. The undergrowth of Robinia is represented by shrubs: *Ligustrum vulgare L., Rubus caesius L., Sambucus nigra L.* The tree-shrub formation provided a successful vegetative reclamation due to phytogenic fields (nutrient requirements, temperature regime, humidity, shade density). On the waste heap of "Mine No.8 Novovolinska" artificial forest communities were found, where the main species is *Betula pendula Roth*., and the shrub of *Salix caprea L.* The tree-shrub mixing type with a two-shrub variant is used on the reclamated waste heap of "Mine No 3 Novovolynska": *Robinia pseudoacacia L.* (main species – M), *Sambucus nigra L.* (low shrub — S), *Salix caprea L.* (high shrub – Hs): M-S-Hs-S-M-S-…; S-M-S-Hs-S-M-…

A biometric analysis of the growth parameters of wood species, namely, the height and diameter of trees and crowns in table, was carried out to evaluate the peculiarities of phytogenic fields formation. It is determined that the highest average values of the analyzed parameters are observed on the slopes of the northern exposure. Biometric parameters of trees on the slopes of southern exposure are a little bit lower. It is caused by lower humidity of the surface layer and moisture content of bulk soil compositions. These data are valid for the planting of a single heap of the "Chervonogradska" mine belonging to the Chervonograd mining region of the Lviv-Volyn coal basin. According to the results of taxational analysis of trees on the waste heaps, it was found that the highest parameters are typical of northern slope exposures: Robinia pseudoacacia L. - reclaimed tailings of "Mine No.2 Novovolinska" and "Mine No. 3 Novovolynska" - is about 8.6-91 cm (picture 1). This phenomenon occurs due to the sufficient moisture content in the substrates of the northern slope exposure, as well as favorable microclimatic conditions. The lowest diameters are observed at the top of the heaps, caused by the negative effect of the wind masses, the temperature of the substrate and the aggressive medium.

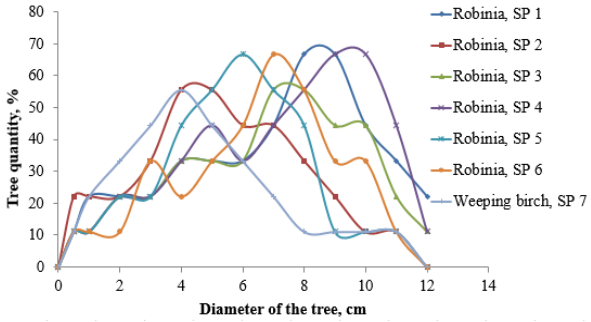
Silvicultural and taxation characteristics of crops of waste heaps phytocoenoses

No.	Substrate	Exposure	Synfolium	Reforestation type	Species	Age, yrs	Diametr, cm	Height, m	Crown diameter, m
Recultivated waste heap of "Mine №2 Novovolynska"									
1	Soil mix	northern	medium	artificial	*Robinia pseudoacacia*	25	$8.6^{\pm0,4}$	$9.7^{\pm0,2}$	$2.5^{\pm0,2}$
2	Soil mix	–	upper plateau	artificial	*Robinia pseudoacacia*	25	$5.5^{\pm0,3}$	$6.5^{\pm0,2}$	$2.2^{\pm0,5}$
3	Soil mix	southern	medium	artificial	*Robinia pseudoacacia*	25	$7.2^{\pm0,4}$	$7^{\pm0,2}$	$2.2^{\pm0,2}$
Recultivated waste heap of "Mine №3 Novovolynska"									
4	Soil mix	northern	medium	artificial	*Robinia pseudoacacia*	26	$9.1^{\pm0,4}$	$10^{\pm0,2}$	$2.6^{\pm0,2}$
5	Soil mix	–	upper plateau	artificial	*Robinia pseudoacacia*	26	$5.6^{\pm0,2}$	$6.3^{\pm0,2}$	$2.0^{\pm0,2}$
6	Soil mix	southern	medium	artificial	*Robinia pseudoacacia*	26	$7.3^{\pm0,4}$	$7^{\pm0,2}$	$2.5^{\pm0,2}$
Recultivated waste heap of "Mine №8 Novovolynska"									
7	Soil mix	northern	medium	artificial	*Betula pendula*	All ages	$4.6^{\pm0,4}$	$9.5^{\pm0,2}$	$2.5^{\pm0,2}$

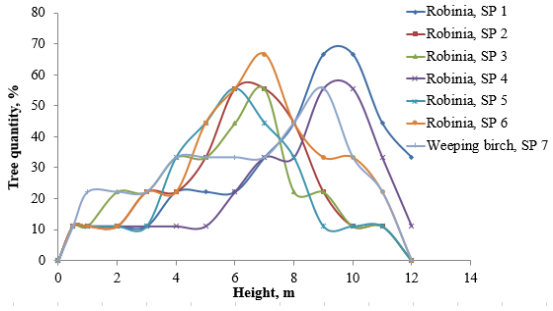
The maximum height of trees (9.5-10 m for all wood species) is also found on the northern exposures of the slopes of waste heaps. At the top of the reclaimed heaps, the height of the trees is lower and averages 6.5 m (picture 2). By the diameter of crowns, the trees were distributed as follows: in the northern slope exposures the diameter of the crowns is 2.5, on the top - 2.0 m, on the southern slope - 2.2 m (picture 3).

At different stages of succession some species aggregate (cluster of individuals), that is, the clumped distribution of individuals in the population is pronounced. At the pioneer stage on damping waste heaps, an aggregation is characteristic for *Plantago lanceolata*; in simple phytocenosis - *Artemisia absinthium, Plantago lanceolata, Trifolium campestre*; in complex phytocenosis - *Artemisia vulgaris, Arctium lappa,*

Trifolium pratense, Calamagrostis epigeios, Daucus carota. The even distribution is inherent for phytocoenoses on reclaimed tailings, namely for *Robinia pseudoacacia*. Random distribution is typical for a significant number of populations, in particular *Tussilago farfara, Chamomilla suaveolens, Taraxacum officinale*. The same way, ruderalcenoses form their own phytogenic field.

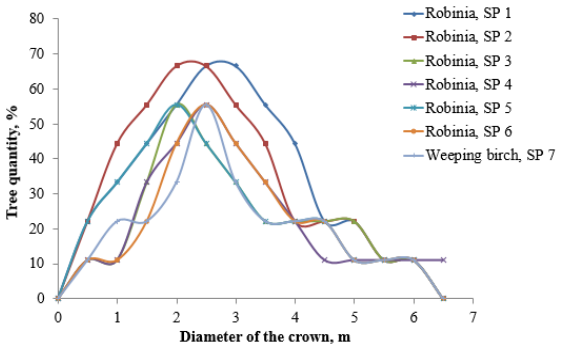


Picture 1 – Diameter of the trees on the survey plot

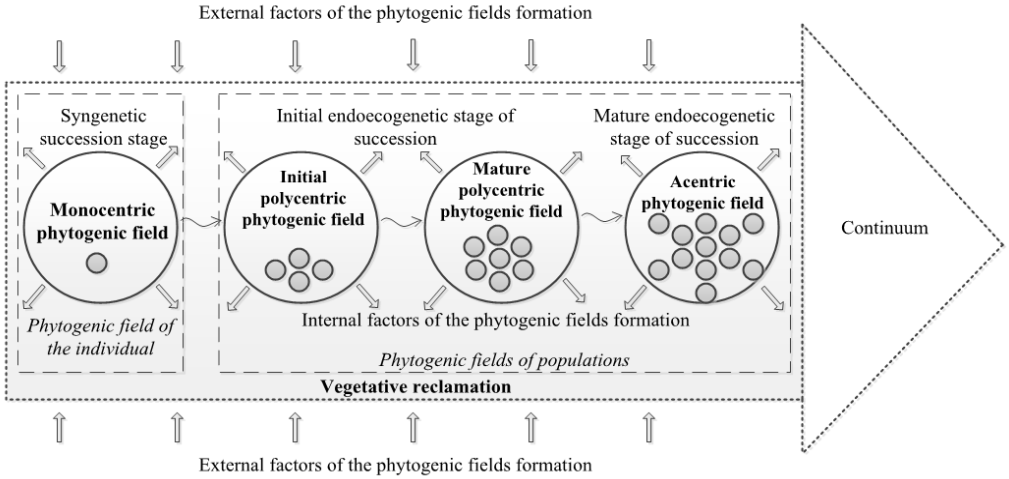


Picture 2 – Height of the trees on the survey plot

Picture 3 – Diameter of crowns of the trees on the survey plot



The phytogenic field makes evident in the continuous life of phytocoenoses, which support the continuum - a wide overlap of ecological amplitudes and the dispersion of population distribution centers along the gradient of the medium [20]. Vegetation distribution in populations may be: random (spontaneous), uniform and uneven. Random distribution occurs only in a homogeneous environment where plants strive to unite into groups. A uniform distribution is observed with strong competition and causes steady reproduction. Uneven (group) distribution is inherent to the plants intent to group formation. In this case, the distribution is close to the random [21, 22]. Theoretical aspects of the phytogenic field formation on the waste heaps of coal mines are shown in picture 4.



Picture 4 – Theoretical aspects of the phytogenic field formation on the coal mines tailings

The floral composition of the formed groups is largely depends on the conditions of the species cites - edafic and microclimate conditions. In this case, the vegetation due to aggregates creates its own phytogenic fields. The investigation of phytogenic fields on devastated landscapes of the waste heaps and coal mines tailings will also improve the bioindicative methods of forest plantations research on the surface and create innovative methods of handling.

Results of artificial phytocoenoses-meliorants and phytogenic fields research. The research of ecological safety of phytogenic fields make it possible to assess the suitability of waste heaps for afforestation, regardless of the country they are formed in. As it turned out, vegetative reclamation and phytogenic fields are inextricably linked. The phytogenic field is formed around a single plant and develops over time, combining the phytogenic fields of other individuals. Thus, plants on the waste heaps of coal mines themselves form an environment for development and reproduction. At the moment of research it was possible to evaluate the substance, energy and information component of the phytogenic field. Taking into account the environment beginning to change by the cenosis, vegetative reclamation investigates the transformation of biotic, geophysical, geochemical flows, as well as improves the aesthetics of the environment and attractiveness. The phytogenic field is a theoretical aspect of evaluating of plant cover formation. Vegetative reclamation is a practical aspect of the evaluation of the phyto-coenoses development, which, due to changes in geoprocesses, improves the attractiveness of the devastated landscapes. In order to assess the environmental safety of the phytogenic fields formation on the waste heaps of coal mines, it is necessary to take into account the microclimate and edaphotope factors. Substantial interest about the phytogenic fields formation is represented by the damping tailings. On these types of waste heaps, the forming syngenesis is under the influence of thermal regimes and insufficient humidity of the substrate. Here, the phytogenic fields, obviously, are formed with the involvement of drought-resistant species. Further research may be aimed at establishing the internal and external factors for the formation of phytogenic fields on coal mine tailings and the communication with the processes of syngenesis.

Conclusions. The decisive role of the phytogenic field in optimization of the devastated landscapes of coal mining in technogenically transformed environment has been established. Data on the species diversity, structure and trend of ecological succession formed during forest reclamation were obtained. The processes of vegetative reclamation on the waste heaps proceed in two ways: the formation of plant phytocenoses with the involvement of trees (acacia, weeping birch); natural vegetation with the involving of autochthonous species. Forest-taxonomic indicators of phytocoenoses formed in the process of artificial vegetative reclamation have been analyzed. These data make it possible to distinguish the ecological safety of places of tree-and-shrub vegetation on the surface of the waste heaps. The phytogenic field here is manifested in the continuous life of phytocoenoses. The structure of the phytogenic field in artificial phytocoenoses depends on the succession stage.

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КӨМІР ШАХТАЛАРЫНЫҢ ТЕРРИКОНДАРЫНДА ФИТОГЕНИКАЛЫҚ ӨРІСТЕРДІ ҚАЛЫПТАСТЫРУДЫҢ ЭКОЛОГИЯЛЫҚ ҚАУІПСІЗДІГІ

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ЭКОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ ФОРМИРОВАНИЯ ФИТОГЕННЫХ ПОЛЕЙ НА ТЕРРИКОНАХ УГОЛЬНЫХ ШАХТ

Аннотация. Цель исследования – изучить особенности формирования фитогенных полей естественных и искусственных насаждений кустарниковой и рудеральной растительности на отвалах угольных шахт в пределах Нововолынского горнопромышленного района (Украина). Биометрический анализ роста искусственных насаждений на отвалах проводился по методике, которая включает закладку временных экспериментальных площадок, измерение диаметра древесных пород на высоте 1,3 м общей высоты деревьев и параметров кроны. Вариация применялась для изучения пространственной структуры растительности на рекультивированных и затухающих отвалах. Приведены модели искусственных фитоценозов и мелиорантов на отвалах угольных шахт, образующихся при лесомелиорации.

В статье представлен анализ лесоустроительных характеристик фитоценоза сельскохозяйственных культур на отвалах. Установлена пространственная структура фитогенных полей по изменчивости наиболее распространенных видов в естественных и искусственных насаждениях на отвалах. Это позволяет подобрать ассортимент пород для проведения эффективной фитомелиорации на поверхности отвалов. В статье представлены результаты исследований по формированию фитогенных полей на отвалах угольных шахт, которые предполагают образование сообществ растений. Доказано, что формирование фитогенных полей неразрывно связано с фитомелиорацией. Проведенное исследование происхождения и распространения фитогенных полей позволяет оценить степень пригодности отвалов для облесения независимо от страны, в которой они образованы. Исследование фитогенных полей на терриконах и отвалах угольных шахт улучшит методологию биоиндикационных исследований для изучения лесных культур на их поверхности и предложит инновационные методы обработки данных. В частности, можно повысить уровень экологической безопасности и эстетики опустошенных территорий, а также снизить затраты на фитомелиорацию.

Ключевые слова: экологическая безопасность, фитогенное поле, угольная шахта, породный отвал, фитоценоз, лесные культуры, мелиорация.

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