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ECOLOGICAL EVALUATION OF REMEDIATION EFFICIENCY OF VILNOHIRSK MINING AND METALLURGICAL PLANT

One of the important tasks of reclamation activities is activation of the natural regeneration or purposeful formation of environmentally sustainable artificial ecosystems that are valuable in economic, environmental, and esthetic terms.

Purpose. To assess the reclamation quality of the mining area of the Vilnohirsk Mining and Metallurgical Plant to predict the potential for restoring the ecological functions of the technologically disturbed ecosystem. The object of the study was the reclaimed soils of Vilnohirsk Mining and Metallurgical Plant, for which the basic physical and chemical characteristics were studied based on the established procedures; the results are presented in the form of schematic cartograms of the thickness of the humus layer and underlying rocks.

Methodology. To implement the ecological direction of reclamation of mining territories, a landscape-ecological approach is used, taking into account the need to improve the environmental condition of the area by arranging agricultural land or forest plantations, ordering the territory for recreational needs. For the purpose of soil agrochemical study, soil samples were selected for agrochemical analyses, such as humus content, water extraction, particle composition, and soil moisture.

Findings. The results of the study demonstrated that during the technical stage of land reclamation of Vilnohirsk Mining and Metallurgical Plant, an artificial soil was obtained similar in its physical and chemical characteristics to the natural zonal middle-loamy chernozem on loess-like subsoil that existed within this site before mining operations were carried out. Although this reclaimed soil is somewhat less fertile, it can be used for afforestation purposes. The absence of topsoil salinization indicates the similarity of its main physical and chemical characteristics to the zonal virgin chernozem. Thus, the technical stage of reclamation of this site was performed at the appropriate level. The reclaimed soil was characterized by physical and chemical properties positive from an environmental point of view (no salinization, humus content value, physical properties). It can be predicted that forest woody species planted in the future on this site will contribute to naturalization and ensure the sustainable development of the newly formed artificial ecosystem.

Originality. It is proposed to take into account the environmental conditions suitable for soil biota development when assessing remediation quality. These animals make a significant environmental contribution to positive transformation of soil ecological features.

Practical value. The performed scientific work is a part of current integral ecological task on providing a human with a set of material and intangible services – natural resources and healthy environments.

Keywords: *reclaimed soil, soil bonitation, mining, Vilnohirsk Mining and Metallurgical Plant*

Introduction. Environmental protection, rational use of natural resources, and ensuring of environmental safety of human life are essential conditions for the sustainable economic and social development of European countries. Increased human pressure on natural environments has escalated worldwide; it induces loss of biodiversity, destruction of native complexes and degradation of important ecosystem functions. Such processes cause significant economic damage and pose a real threat to human life and health. As a result of coal mining, the lands intended for are withdrawn from agricultural use. Thus, such lands are replaced by man-made landscapes, i.e. dumps and open-cuts, which are characterized by subsidence, highly mineralized groundwater table rise, acid mine drainage, toxic contamination. These factors affect wide range of species and biological diversity within territories disturbed by production activities. Disrupted lands developed during coal mining can be partially restored by remediation. The loss of ecosystem services may be irreversible with the current rate of nature degradation. At the local level, replacement of ecosystem functions by technical means is in most cases more expensive than restoration of natural ecosystems. Ecosystem functions, including environment-forming, are not only implemented by environmental communities and ecosystems, but also by individual animal species and their populations. Currently, theory and practice of ecosystem services assessment that are focused on improving the environment quality are the least developed,

particularly in regard to environment-forming functions of biota when carrying out reclamation activities [1].

Territories disturbed by mining activities can be restored by reclamation. Directions of restoration of anthropogenically transformed geosystems were determined on the basis of establishing their suitability for a certain type of economic development, such as agricultural, forest and water management, recreational, environmental, construction, and others. The measures of mining reclamation involve reducing the areas alienated for the mining activities to a rational minimum; use of equipment and compliance with technology that ensure maximum reduction of the harmful impact of mining operations on the environment; selective removal and storing of humic topsoil; separate excavation of overburden and toxic parent rocks; formation of dumps and covering their surface with a layer of fertile soil or placement of external dumps in ravines, gullies and other unsuitable areas; restoration or construction of new access roads to the reclaimed territory.

An important task of reclamation measures is acceleration of natural regeneration or purposeful formation of artificial ecosystems that are environmentally sustainable and valuable in economic, environmental, esthetic respects. Among ecosystem functions, due to the activity of the soil invertebrates, of special interest is the study of the animal effect on long-term cumulative processes such as soil structure, its microzonality, structure of microbial communities that affect soil stability and fertility. Soil biota not only provides the implementation of certain important ecosystem services that accelerate the re-

covery of both soils and ecosystems in general within the coal mining sites [2], but also it is associated with the soil physical and chemical gradients (temperature, humidity, acidity, salinity, exchange capacity, and so on), and also affects them by transforming the soil as a habitat. This soil-forming function of animals is an important biogeocenotic (ecosystem) process associated with the environmental and environmental-transforming activity of animals and their communities.

Literature review. Vilnohirs'k Mining and Metallurgical Plant is a mining and processing and metallurgical enterprise in Ukraine, operating on the basis of the Malyshevskiy (Samotkanskyy) placer deposit of tertiary-age sands with ilmenite, rutile, and zircon. It is a leading enterprise in the metallurgical industry of Ukraine due to production of rare metal concentrates. It is the raw material base of a number of sectors important for the Ukrainian economy, such as chemical, electrical and engineering ones.

Overburden rocks are dense greenish-gray and reddish-brown clays, yellowish-brown and pale-yellow loess-like loams. Ore is represented by quartz fine-grained sands with a clay fraction of 10 to 45 % and the amount of heavy minerals up to 15–20 %. The small capacity of overburden rocks determined the open-pit mining method. Mine development is carried out by a quarry method using a rotary complex.

The basic approach to scientific research was a comprehensive approach to the problem of ecosystem services, which determines the transition to new ecocentric concept of nature management; it is needed to conserve the natural mechanisms of regulation and highlights the key value of environment-forming functions of the nature and the need for its integration into economy. The works by leading scientists have determined ecological role of soil invertebrates involved in stability formation of anthropogenically transformed ecosystems, as “centers of pedogenic processes” [3]. Of particular scientific interest is the study of organic matter addition and earthworm inoculation effects on the biological activity of soil contaminated with mobile forms of heavy metals [4]. Some scientists noted that pure mine spoil often has a high density, low structure rate, as well as high salinity of water extracts, which together leads to extremely low suitability of such mine spoil application as substrate for living of soil biota [5]. For this reason, the pure mine spoil is covered with remediation layer from non-toxic material (non-saline loess-like loam, clay) in the process of reclamation. The next stage of remediation activity is application of fertile humic layer onto the mine spoil. On the territory of steppe Ukraine, humic mass of ordinary chernozem or humusless substrates are usually applied for this purpose.

At the biological stage of reclamation, herbaceous, tree and shrub plantations are planted on artificially created soil [6]. Numerous living animals dwelling in the soil [7], particularly representatives of saprotrophic complex, play an important role in development of the artificial soil stability. Previous studies showed that the life activity of soil invertebrates in anthropogenically transformed areas has a positive effect on the ecological properties of soils [7, 8]. Under conditions of technogenically disturbed ecosystems, this transforming function of animals contributes to positive changes in their ecological status, leads to naturalization of artificial ecosystems under conditions of industrial zones. Subsequently, the conditions of newly formed artificial ecosystems influence the life activity of the animal community [9].

To implement the ecological direction of reclamation of mining territories, a landscape-ecological approach is used which allows the adoption of the most appropriate method of mining and biological reclamation to determine the further effective use of land, taking into account the need to improve the environmental condition of the area by arranging agricultural land or forest plantations, ordering the territory for recreational needs, and others. It is planned that the study area will be used for forest planting.

Forest remediation is one of ways for optimization of technogenically disturbed lands. According to the modern concept of land remediation, forest remediation is carried out in the

absence of reasonability to recycle the land for agricultural use. The main purposes of forest remediation are the increasing of forest fund and the improvement of environment. Environmentally, the main task of the reclamation is creation of sustainable forest plantations that have a powerful environment-forming effect on technogenically disturbed sites [10]. Forest remediation is the most effective method for the recovery of disturbed lands under steppe conditions; after its performing will be a dramatic increase in the forest area of the damaged territory, because the forest provides a reliable water retention, reduces wind strength, redistributes better the summer and winter precipitation, conversion surface runoff waters into deep runoff waters, leveling of temperature regimes, and so on.

Purpose. The purpose of the work was to determine the suitability of reclaimed lands of Vilnohirs'k Mining and Metallurgical Plant for growing forest plantations and further naturalization. The subject of the study presented was assessment the remediation quality in order to identify the conditions for planting of woody plants and further natural population of soil invertebrates living. The object of the study was recultivated soils of Vilnohirs'k Mining and Metallurgical Plant; the main physical and chemical characteristics were studied. Since soil is the basis of any terrestrial ecosystem that determines direction of development and features of ecosystem functioning, the rate of its formation determines the rate of recovery of all other ecosystem components and functioning conditions (bacteria, plant and animal communities). Therefore, the efficiency of forest ecosystem recovery can be estimated by the rate of soil formation and environmental properties of the root layer created during the remediation process. We mean soil-forming process as the way of the initial substrate transformation by interaction of all soil-forming factors.

Methods. The research was conducted on the cartographic basis of 1:25,000 scale mining plans. The data of soils field survey were obtained by specialists of State-Owned Enterprise “Dnepropetrovsk Institute of Land Management”. Each plot was divided into some squares where pits and wells were staked angularly. With the purpose of soil agrochemical study, 12 profile pits were placed, from which the soil samples were selected for the following agrochemical analyses of humus content (GOST 26215-84), water extraction (GOST 26422-85 – GOST 26428-85, particle composition, soil moisture. For the analysis of soil organic matter, soil samples (0–15 cm depth) were collected in plastic bags, stored in insulated containers and returned to the laboratory. Each sample was dried at 40 °C. Organic carbon was determined according to Turin's modified method (acid-dichromate digestion, 120 °C, 45 min, in a thermostat, catalyst Ag_2SO_4). The following cartograms were prepared: thickness of humic layer, underlying rocks.

Brief description of the mining and technical stage of reclamation. The square of reclaimed lands of Vilnohirs'k Mining and Metallurgical Plant is 60.0 ha. Mining and technical reclamation of the surveyed areas were carried out by Vilnohirs'k Mining and Metallurgical Plant.

Loess-like loam and loess were the most common subsoil. Loess deposits of the studied area were represented by a carbonate pale and yellowish-pale loam. Loess rocks are the most favorable underlying rocks in reclamation process, but during mining activity they were often mixed with red-brown clays. Red-brown clay included rocks of rather heavy mechanical composition. The analysis of water extracts demonstrates the presence of easily soluble salts in red-brown clays, which together with compactness causes their water and air permeability.

In place of reclamation areas, fine-textured low-humic low-washed ordinary chernozem and fine-textured low-humic ordinary chernozem had previously been formed. Such soil type is characterized by the following main indicators.

1. Fine-textured low-humic ordinary chernozem on loess: the depth of organic layer including all humus horizons ($H + H_p$) was 69 cm; humus content in the plow horizon was 3.6 %; content of physical clay in the plow horizon was 39.6 %.

A quality score was 87; taking into account the environmental factor, it amounted to 43.

2. Fine-textured low-humic ordinary chernozem on loess: depth of humus horizons ($H + Hp$) was 47 cm; humus content in the plow horizon was 3.39 %; content of physical clay humus content in the plow horizon was 39.8 %. A quality score was 83; taking into account the environmental factor, it amounted to 41.

Assessment of the remediation quality was performed by comparing bonitet scores of reclaimed lands and zonal native soils. In this area, low-humus middle loamy ordinary deep chernozem on loess was taken as reference soil for bonitation of reclaimed lands. This soil type is characterized by the following main parameters: humic horizons thickness ($H + Hp$) of 85 cm; humus content in the topsoil of 5.1 %; content of physical clay in tilth topsoil of 40.0 %. A quality score was 80; taking into account the environmental factor, it amounted to 39. The above data are used in assessment of reclaimed lands. Evaluation of effectiveness of land reclamation is an integral part of soil and agrochemical survey, and it includes bonitation of reclaimed soil.

Results. Characterization of reclaimed soil. Slope of surface of the surveyed area in the northern part does not exceed 1° , and in the southern part it exceeds 3° . Microdepressions and other kinds of surface subsidence have not been observed. The surveyed reclaimed area was presented by the one whole plot.

Topsoil quality. Applied humic layer is represented by a mixture of humic and transitional horizons of deep low-humus heavy loamy ordinary chernozem, low and medium eroded. Humus content within 0–10 cm of depth varied from 2.8 to 4.0 % with the average of 3.4 %. Humic layer varied in thickness from 40 to 63 cm. On average, the depth of the bulk fertile layer is 50 cm (Figure, a). Structure of profile of filled recultivated soils is characterized by two separate layers with a sharp boundary between them. Soil profile description: $H - Hp$ 0–50 cm – humic, gray-coloured, cloddy, fluffy, fresh, with sharp transition; Pk 50–100 cm – subsoil, technogenic mixture of loess-like loams and red-brown clays. Salinization with water-soluble salts above the toxicity threshold in tilth topsoil

was not detected. The soil was compacted below the plow pan. Calcium carbonates were observed throughout the soil profile.

The underlying rocks. The rocks underlying the humus layer are represented by loess loam and technogenic mixture of loess-like loam and red-brown clay. The investigated rocks of the remediation site contain no water-soluble salts above the toxicity threshold. Long-term studies of recultivated lands have not revealed the negative impact of nonsaline loess rocks on soil productivity. In conditions of the investigated remediated site of Vilnohirsk Mining and Metallurgical Plant, influence coefficient was equal to 0.98.

Mechanical composition of soil. Mechanical composition of remediated soils of Vilnohirsk Mining and Metallurgical Plant is shown in Figure. Analyzing the data represented, the following should be noted:

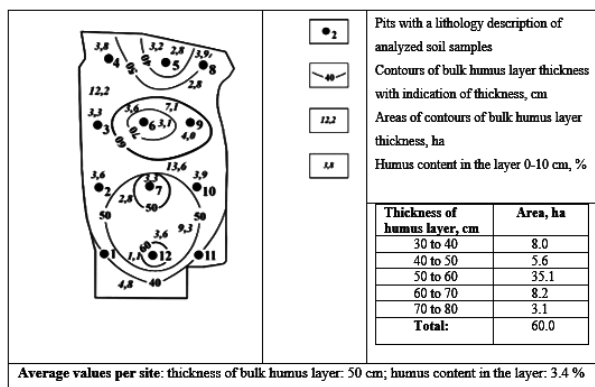
1. Mechanical composition of the bulk humus layer is middle loam and light loam.

2. Mechanical composition of the underlying rocks is mainly heavy loam, sometimes light loam. Average content of physical clay in the 0–100 cm layer was 49.3 %.

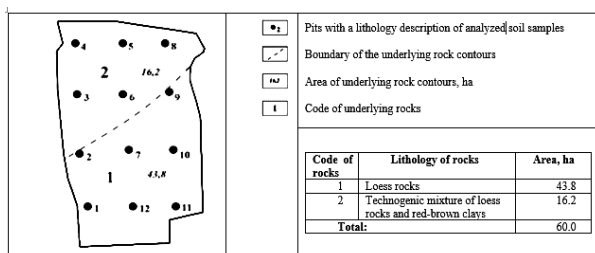
Salinity of reclaimed soil. Salinity of this soil can be closely associated with the process of mixing of various soil and parent rock layers during the mining.

Analysis of water extracts of reclaimed soils of Vilnohirsk Mining and Metallurgical Plant revealed no presence of water-soluble salts above toxicity threshold in the underlying rocks. The underlying rocks were characterized as non-saline. Such rocks do not cause a negative impact on reclaimed bulk soils. The coefficient of salinity impact was equal to 1.00. The humus soil layer was also non-saline. In the absence of salinity, corresponding map of salinity of the reclaimed soil was not compiled.

Evaluation of reclaimed soil. During the soil bonitation process, a bonitation scale is used with 100 points to denote the most suitable (the most fertile soil) soil within the area studied. Territorial-specific correction coefficients are used to account for soil processes that significantly affect yields but cannot be sufficiently identified using routine quantitative methods. Initially, three first parameters can be used for calculation of total bonitation score of reclaimed land, followed by the use of other parameters of soil fertility as correction coefficients. The following characteristics of reclaimed soil properties were used to determine the score of bonitet (average on the site, Table 1). The studies conducted have shown that the remediation measures on the territory of Vilnohirsk Mining and Metallurgical Plant (by the example of the investigated site) were carried out at the proper level. As a result of mining operations, topsoil of reclaimed soil was depleted in chemical elements necessary for plant growth; as a result, the soil becomes more calcareous, and contains humus by 1.5–2 times less than that topsoil of the native soil. Topsoil thickness was on average 50 cm. Average humus content in the filled layer was 3.4 %. The soil was compacted below the plow pan. The underlying layer is represented by loess rocks (43.8 ha) and a man-made mixture of loess rocks and red-brown clays (16.2 ha). According to the results of the calculation of bonitet scores (Table 2), the final score of reclaimed soil, taking into



a



b

Fig. Cartographic representation of thickness of humus layer and humus content (a) and underlying rocks (b) on the reclaimed site

Table 1
Parameters of reclaimed soil properties of Vilnohirsk Mining and Metallurgical Plant

Parameter	Parameter value
Humus layer thickness, cm	50
Humus content in the layer of 0–10 cm, %	3.4
Content of physical clay in the layer of 0–100 cm, %	24.9
<i>Correction factors for:</i>	
- underlying of rocks	0.98
- salinization	1.00

Calculations of bonitet scores by properties of remediated soils of Vilnohirsk Mining and Metallurgical Plant

Name of soil	Properties of soil and its assessment, in scores									Score on soil properties	Correction factors for:		Final score	
	depth of humic horizons			humus content in the topsoil			content of physical clay				underlying	salinity	Without environmental coefficient	With environmental coefficient of 0.49
	actual, cm	score	Equity impact	actual, %	score	Equity impact	actual, %	score	Equity impact					
Ordinary deep low-humus middle loamy chernozem on loess	85	–	–	5.1	–	–	40.0	–	–	80	–	–	80	41
Reclaimed soils (average on site)	50	58.8	48.8	3.4	66.7	49.3	24.9	46	25.3	58.2	0.98	1.00	57	27.9

account the environmental coefficient, was 27.9 compared to 41 points of the zonal soil.

Salinization with water-soluble salts above the toxicity threshold in the arable layer of the studied soils was not found. Analysis of water extracts of underlying rocks revealed the presence of water-soluble compounds above the water solubility limit. Remediated soils were non-saline in the whole area. Calcium carbonates were observed throughout the soil profile.

Conclusions. The results of the study demonstrated that during the technical stage of land reclamation of the lands impacted by Vilnohirsk Mining and Metallurgical Plant activity, an artificial soil was obtained similar in its physical and chemical characteristics to the natural zonal middle-loamy chernozem on loess-like subsoil that had been located within this site before the mining operations. Although this reclaimed soil is somewhat less fertile, it can be used for afforestation purposes. The absence of salinization of the upper layers of the soil indicates the proximity of its main physical and chemical characteristics to the zonal natural Chernozem.

Thus, the results of the studies performed showed that the technical stage of reclamation of this remediated site was performed at the proper level. Reclamation soil was characterized by physical and chemical properties that are positive from an environmental point of view (no salinization, proper humus content and physical properties). This indicates the closeness of the studied physical and chemical characteristics to the zonal natural chernozem. It can be predicted that forest woody species planted in the future on this site will contribute to naturalization and ensure the sustainable development of the newly formed artificial ecosystem.

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Екологічна оцінка ефективності рекультивациі земель Вільногірського гірничо-металургійного комбінату

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Прискорення природної регенерації або цілеспрямоване формування екологічно стійких і цінних у господарському, природоохоронному, естетичному відношенні штучних культурбіогеоценозів є одним із важливих завдань рекультивацийних заходів Вільногірського гірничо-металургійного комбінату як провідного підприємства металургійної галузі України із виробництва кон-

центратів рідкісних металів. Він є сировинною базою ряду важливих для економіки України галузей, таких як хімічна, електротехнічна й машинобудівна.

Мета. Оцінка якості рекультивациі території видобутку Вільногірського гірничо-металургійного комбінату з метою прогнозування потенціалу відновлення екологічних функцій техногенно порушеної екосистеми. Об'єктом дослідження виступали рекультивовані ґрунти Вільногірського гірничо-металургійного комбінату, для яких досліджувались основні фізико-хімічні характеристики за загальноприйнятими методиками; результати представлено у вигляді схематичних картограм потужності гумусованого шару й підстилаючих порід.

Методика. Для реалізації екологічного напрямку рекультивациі гірничих територій застосовується ландшафтно-екологічний підхід з урахуванням необхідності покращення екологічного стану місцевості шляхом упорядкування сільськогосподарських угідь або лісових насаджень, упорядкування території для рекреаційних потреб. Для агрохімічного дослідження ґрунту відбирали зразки ґрунту для проведення агрохімічних аналізів, таких як вміст гумусу, вилучення води, склад частинок і вологість ґрунту.

Результати. Дослідження продемонстрували, що у ході технічного етапу рекультивациі земель Вільногірського гірничо-металургійного комбінату було одержано штучний ґрунт, що за фізико-хімічними характеристиками є подібним натуральному зональному чорнозему звичайному малогумусному глибокому середньосуглинковому на лесах, що існував на цій ділянці до проведення гірничо-видобувних робіт. Хоча рекультивований ґрунт має дещо меншу родючість, він може використовуватися з метою лісорозведення. Відсутність засолення верхніх шарів ґрунту свідчить про близькість його основних фізичних і хімічних характеристик до зонального природного чорнозему. Таким чином, технічний етап рекультивациі даної ділянки рекультивациі виконано на належному рівні. Рекультивований ґрунт характеризується фізико-хімічними властивостями, позитивними з екологічної точки зору (відсутність засолення, вміст гумусу, фізичні властивості). Це свідчить про близькість досліджених фізичних і хімічних характеристик до зонального природного чорнозему. Можна прогнозувати, що лісові породи, висаджені у майбутньому на цій ділянці, сприятимуть натуралізації та забезпечать сталий розвиток новоутвореної штучної екосистеми.

Наукова новизна. Полягає в тому, що при оцінці якості рекультивациі пропонується врахувати екологічні умови, придатні для розвитку ґрунтової біоти. Ці тварини вносять значний екологічний внесок у позитивну трансформацію екологічних особливостей ґрунту.

Практична значимість. Виконана наукова робота є частиною поточного цілісного екологічного завдання щодо забезпечення людини набором матеріальних і нематеріальних послуг – природних ресурсів і здорового середовища.

Ключові слова: рекультивовані ґрунти, бонітування ґрунтів, видобувна промисловість, Вільногірський гірничо-металургійний комбінат

Экологическая оценка эффективности рекультивации земель Вольногорского горно-металлургического комбината

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Ускорение естественной регенерации или целенаправленное формирование экологически устойчивых и ценных в хозяйственном, природоохранном, эстетическом отношении искусственных культурбиогенотозов является одной из важных задач рекультивационных мероприятий Вольногорского горно-металлургического комбината как ведущего предприятия металлургической отрасли Украины по производству концентратов редких металлов. Он является сырьевой базой ряда важных для экономики Украины отраслей, таких как химическая, электротехническая и машиностроительная.

Цель. Оценка качества рекультивационной территории добычи Вольногорского горно-металлургического комбината с целью прогнозирования потенциала восстановления экологических функций техногенно нарушенной экосистемы. Объектом исследования выступали рекультивированные почвы Вольногорского горно-металлургического комбината, для которых исследовались основные физико-химические характеристики по общепринятым методикам; результаты представлены в виде схематических картограмм мощности гумусного слоя и подстилающих пород.

Методика. Для реализации экологического направления мелиорации шахтерских территорий используется ландшафтно-экологический подход, учитывающий необходимость улучшения экологического состояния территории за счет организации сельскохозяйственных угодий или лесных насаждений, заказа территории для рекреационных нужд. В целях агрохимического исследования почвы образцы почвы были отобраны для агрохимических анализов, таких как содержание гумуса, извлечение воды, состав частиц и влажность почвы.

Результаты. Исследования показали, что в ходе технического этапа рекультивационной земель Вольногорского горно-металлургического комбината была получена искусственная почва, по физико-химическим характеристикам схожая с природным зональным черноземом обыкновенным малогумусным глубоким среднесуглинным на лесах, существовавшим на данном участке до проведения горнодобывающих работ. Хотя рекультивированная почва имеет несколько меньшее плодородие, она может использоваться в целях лесоразведения. Отсутствие засоления верхних слоев почвы свидетельствует о сходстве ее основных физических и химических характеристик с зональным природным черноземом. Таким образом, технический этап рекультивационной этого участка был выполнен на должном уровне. Рекультивированная почва характеризуется физико-химическими свойствами, положительными с экологической точки зрения (отсутствие засоления, содержание гумуса, физические свойства). Можно прогнозировать, что лесобразующие породы, высаженные в будущем на этом участке, будут способствовать натуралізації и обеспечить устойчивое развитие новой искусственной экосистемы.

Научная новизна. Заключается в том, что при оценке качества восстановительных работ предлагается учитывать условия окружающей среды, подходящие для развития почвенной биоты. Эти животные вносят значительный экологический вклад в положительную трансформацию экологических особенностей почвы.

Практическая значимость. Выполненная научная работа является частью текущей комплексной экологической задачи по обеспечению человека набором материальных и нематериальных услуг – природных ресурсов и здоровой окружающей среды.

Ключевые слова: рекультивированные почвы, бонитировка почв, добывающая промышленность, Вольногорский горно-металлургический комбинат

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