Technosols as a resource for restoration of soil and vegetation cover during disturbed land reclamation in the forest-steppe zone

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Abstract. Technogenically disturbed soils of the Kedrovsky coal mine dumps, a branch of JSC MC Kuzbassrazrezugol, located in the forest-steppe of the Kuznetsk Basin, Kemerovo region (Russia), are investigated. The physicochemical characteristics of young soils were studied using the facilities of an experimental polygon for disturbed land reclamation technologies. The following soil variants were studied: typical technosol (technogenic eluvium), organogenic technosol (with application of a potential fertile soil layer, PFSL), and humusogenic technosol (with application of a fertile soil layer, FLS). The humusogenic technosol was found to possess a higher starting lithogenic potential in terms of soil formation, when restoring disturbed soils and their vegetation cover with an increase in species diversity by zonal type. Under favorable climatic conditions and the use of proper agrotechnical technologies, FSL technosols promote the development of grassy ecosystems and activate the process of soil formation. Over time, these soils can approach zonal soil types in terms of their main physical and chemical parameters, including organic matter.

1 Introduction

The Kemerovo region is one of the most industrially developed areas in Siberia. This region hosts a large number of coal mining enterprises, underground and open-pit mines. Coal is extracted from high-capacity seams, which leads to critical changes in the terrain and microclimate, as well as to soil liquidation. The enormous impact of mining enterprises on the environment requires immediate measures; otherwise, these areas may receive the status of ecological disaster zones in the nearest future [1].

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Although the problem of ecosystem degradation has a global character, it acquires particular urgency in such regions as Kuzbass. Here, the decades of extensive industrial development have led to an acute ecological crisis in nature management. At present, no less than 70% of the soil agricultural cover has been transformed to some extent, with about 100 thousand hectares of land having been completely destroyed. The sites with a destroyed soil cover form technogenic landscapes, gradually transforming into natural and technogenic complexes with a different ratio of natural and anthropogenic components [2, 3].

Natural and technogenic complexes with technogenic formations (technosols) are characterized by a different starting lithogenic potential for restoration of the soil and vegetation cover during reclamation of disturbed areas in different soil-bioclimatic regions and soil zones. This potential depends on the composition of soil-forming rocks and the presence of organic carbon, which undoubtedly affects the rate of soil cover restoration [4].

In this work, we investigate the properties of technosols within the forest-steppe zone of Kuzbass as a starting resource for the restoration of its soil and vegetation cover. The study is conducted using the facilities of an experimental polygon for testing different reclamation technologies with different soil-amendment approaches.

2 Materials and Methods

The research objects were technogenically disturbed soils of waste rock dumps at the Kedrovsky coal mine, a branch of JSC MC ‘Kuzbassrazrezugol, located in the subzone of the northern forest-steppe of the Kuznetsk Basin, Kemerovo region (Russia). This area attracts particular research interest due to the presence of a large number of coal mining enterprises. Such enterprises pose a major threat of destruction to forest-steppe and steppe communities, radically transforming natural landscapes and creating technogenic landscapes in their place. The specialists of the Laboratory for Reclamation and Biomonitoring of the Institute of Human Ecology, the Federal Research Center of Coal and Coal Chemistry of the Siberian Branch of the Russian Academy of Sciences, are working on the creation of an experimental polygon for testing technologies for reclamation of disturbed lands by the coal industry on the dumps of Kedrovsky coal mine, a branch of Kuzbassrazrezrezugol, in the forest-steppe zone of the Kemerovo region.

In accordance with the experimental design, different variants of reclamation technologies with different lithogenic compositions of technosols were studied. These technologies are aimed at restoration of young soils and ecosystems in the forest-steppe zone of the Kuznetsk Basin, including:

(1) technogenic eluvium;
(2) technogenic eluvium covered with a layer of potential fertile soil, PFSL;
(3) technogenic eluvium covered with a layer of fertile soil, FLS.

Zonal soil (leached chernozem) was used as a background.

Technogenic eluvium reflects the entire set of the most important ecological conditions of reclaimed dumps, which determine the lithologic and fractional composition, fertility, water-holding capacity, and temperature regime of the formed young soils (technosols). As noted by V.A. Androkhanov and V.M. Kurachev [5], these gradations fully represent the diversity of edaphic conditions that can be simulated under the conditions of coal industry dumps. All the experimental variants were planted with the same types of woody vegetation, including common pine, common mountain ash, Siberian spruce, and common birch. The current reclamation technologies offer methods for creation of woody and herbaceous phytocenoses, which render effective provided the high potential of the initial technogenic substrate. At each experimental site, soil sections of the formed technogenic soils were laid out and samples were taken by layers (or horizons).

In order to establish the initial resource (qualitative composition) of technosols used in the restoration of soil and vegetation cover, the main chemical and physicochemical indicators of soils were determined. The collected samples were examined in terms of their granulometric composition, total organic carbon, humus, soil acidity index (pH of water extract), total absorbed bases, exchange calcium and magnesium cations, as well as nutritional elements, such as total nitrogen, gross and mobile phosphorus. All studies were conducted using standard methods.

3 Results and Discussion

Technogenic soils formed under the influence of reclamation technologies form different technosol subtypes in accordance with the substantive-genetic classification of soils of technogenic landscapes [6]. Within this classification, soils of technogenic landscapes belong to post-lithogenic soils, the class of transformed technosols, the type of technosols, the subtypes of typical, organogenic, humusogenic soils. Technogenic landscapes in Kuzbass are extremely diverse in their physical and chemical properties due to the differences in the genesis and occurrence conditions of rocks subjected to excavation in the process of coal mining [7].

The granulometric composition of technosols is determined by the initial composition of substrates used for covering the dump surface in the experimental polygon (Table 1).

Table 1. Granulometric composition of technosols

Horizon depth, cm	Share of particles (%); diameter, mm						Physical clay fraction <0.01mm	Name by granulometric composition
	1.0–0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001		
Variant 1 Technosol typical								
C 0–10	1.93	8.47	22.4	14.40	28.40	24.40	67.20	Light-clayey fine silty
Variant 2 Technosol organogenic								
C 0–10	13.12	20.08	16.8	12.80	12.80	24.40	50.00	Heavy loamy fine sandy-silt loam
Variant 3 Technosol humusogenic								
A 0–10	1.45	12.95	41.2	12.80	12.40	19.20	44.40	Medium loamy silt-loamy, coarse-silty
AC 30–40	7.85	16.55	29.2	11.20	15.20	20.00	46.40	Тяжелосуглинистый иловато-крупнопылеватый
Background. Zonal soil, leached chernozem								
A 0–40	1.34	14.28	30.64	6.47	33.66	8.46	46.26	Heavy loamy silt and coarse dusty loam

In all investigated technosol subtypes, the ratio of main fractions of granulometric composition remains constant within the entire soil profile. Similar to cover sediments and loess-like loams, the predominant fractions comprise those of silt and coarse dust. In humusogenic technosol, the granulometric composition is initially determined by the composition of the applied FSL. Therefore, the technosols created from these substrates retain almost the same granulometric composition along the depth. All investigated technogenic soils belong to medium-loamy, heavy-loamy, and light-loamy varieties.

The chemical state of soil can be described as a set of its chemical properties and processes occurring therein. The quantitative and/or qualitative chemical state of technosols characterizes their potential ability to provide plants with nutritional components for their normal growth and development. Humus accumulation constitutes the main qualitative feature, which differentiates young soils from their parent rocks. Anthropogenic activity disturbs the existing natural balance and can either promote humus formation, through the inflow of additional amounts of organic residue, or reduce its content as a result of mineralization and erosion intensification. From the standpoint of agrocenoses, the former process has a positive effect (excluding cases of input of fossil organic residues). However, the latter process has a negative effect on both natural and anthropogenic biogeocenoses, being a manifestation of improper nature management. In this case, as indicated by I.N. Gossen and D.A. Sokolov [8], the decrease in the content of specific organic matter in soils will reflect the degree of their anthropogenic degradation.

Coal mine dumps are known to be rich, to a greater or lesser extent, in carbon-containing compounds. In most cases, the enclosing rocks contain more carbonaceous particles. In terms of petrographic composition, the enclosing rocks and their technogenic eluvium, which forms the substrate for the settlement of living organisms and formation of young soils, are represented by siltstones and mudstones in technogenic ecosystems. Conversely, the overburden rocks are frequently brown non-carbonate clays and loess-like loams [9]. In this regard, the total organic carbon content in technosols and a significant variability of humus accumulation in young soils are caused not only by the specificity of humus-accumulative processes, the complexity of macro- and microrelief, and the nature of vegetation cover restoration, but also by specific features of the dump mineral substrate and the diversity of overburden rock composition [10].

The lithogenic resource of humus content variability in the studied technosols changes accordingly to the subtype affiliation of young soils (Table 2).

Table 2. Chemical and physicochemical properties of technosols

Horizon depth, cm	C, %	Humus, %	pH water extract	Cation exchange capacity, meq per 100 g of soil		
				$\Sigma Ca^{2+}+Mg^{2+}$	Ca^{2+}	Mg^{2+}
Variant 1 Technosol typical						
C 0–10	2.18	3.78	8.26	22.22	16.16	6.06
Variant 2 Technosol organogenic						
C 0–10	2.68	4.62	7.83	26.28	22.02	6.06
Variant 3 Technosol humusogenic						
A 0–10	3.40	5.94	7.29	28.28	20.20	8.08
AC 30–40	2.75	4.65	7.67	22.22	12.12	10.10
Background. Zonal soil, leached chernozem						
A 0–40	3.68	6.35	6.92	45.91	38.10	7.81

The carbon content in the technosols of rock dumps is associated with the presence of carbonaceous material. The quantitative value of organic carbon in this case can have a dual origin, both pedogenic and inherited from the soil-forming rock, which was confirmed in the works [11, 12].

According to Table 2, the samples of typical technosol show the lowest humus content, while those of humusogenic technosol show the highest values. The amount of humus in organogenic technosol is only 4.62%. The increased carbon content in the upper horizon of the forming young soil of humusogenic technosol, compared to the parent rock, is associated with the applied soil-improving material as confirmed by the studies of V.G. Dvurechensky and V.P. Seredina [13].

Soil pH is another important indicator of the physicochemical state of young soils. The studied technosols showed predominantly neutral, passing to slightly alkaline, pH water extract values (7.29–8.95). These values characterize satisfactory conditions for both growth and development of plants and biochemical processes in young soils.

The total sum of absorbed bases is an essential characteristic of any soil, including technosol. This parameter depends on the soil granulometric and mineralogical composition, pH value, and humus content. The conducted study of different subtypes of technosols revealed the following regularities: an increase in the humus content and granulometric composition leads to an increase in the total sum of exchangeable cations. Of particular importance is the composition and ratio of exchangeable cations, which depend on the type of soil formation, water–salt regime, composition of parent rocks, and human economic activity. Exchangeable bases have a significant impact on the physical properties of soils and formation of organic-mineral compounds. In initial subtypes of technosols in all experimental variants, the ratio of calcium ions to magnesium ions ranges within 2.5:1, with the predominance of calcium cations. The predominance of calcium in the composition of the soil absorbing complex increases the degree of soil aggregation and contributes to the formation of a water-resistant structure of technosols.

It was established by G.I. Makhonina [14] that, at the initial stages of soil formation, the availability of nutritional elements in technogenic soils is highly important for the development of biological processes. While a continuous vegetation cover has not yet formed on the dumps, the nitrogen content in young soils varies greatly. Its greatest accumulation is confined to areas more overgrown with plants, which is quite natural. In the course of evolution, the process of soil formation is activated and, accordingly, the content of biogenic elements in anthropogenic soils increases (Table 3).

Table 3. Agrochemical properties of the technosol subtypes under study

Horizon depth, cm	Total nitrogen	Gross phosphorus	Mobile phosphorus
	%		mg/100g
Variant 1 Technosol typical			
C 0–10	0.12	0.21	13.0
Variant 2 Technosol organogenic			
C 0–10	0.19	0.27	16.5
Variant 3 Technosol humusogenic			
A 0–10	0.46	0.58	19.0
AC 30–40	0.14	0.33	15.0

In the studied technogenic subtypes of soils, the following regularity in the content of total nitrogen, gross phosphorus and its mobile forms was observed. The content of these elements increases in the row of technosol typical < technosol organogenic < technosol humusogenic. The maximum values of total nitrogen (0.46%) and gross phosphorus (0.58%) are observed in humusogenic technosol, which indicates the strengthening of biological accumulation processes in this direction and is also associated with different variants of reclamation technologies.

4 Conclusion

According to the substantive-genetic classification of soils of technogenic landscapes, the studied technogenic soils of the Kedrovsky coal mine dumps formed as a result of application of various biological reclamation technologies are represented by the following technosol subtypes: typical (without application of soil improvers), organogenic (with application of a potential fertile soil layer, PFSL), humusogenic (with application of a fertile soil layer, FLS). In terms of granulometric composition, these subtypes belong to light loamy, heavy loamy, and light clay varieties. Coarse dust and silty fractions dominate in their granulometric composition.

In terms of all chemical indicators, the lithogenic resource state of the technosols under study differ significantly from zonal chernozem soils, consisting in a lower humus content, a more alkaline reaction of the environment, lower values of the total sum of absorbed bases. The humusogenic technosol with application of a fertile soil layer (FSP) as a soil improver showed the maximum humus content, a more favorable environmental reaction, and an increased content of biophile elements. This characterizes a good starting lithogenic resource of the young soil for restoration of disturbed areas and vegetation cover.

It can be assumed that, under favorable climatic conditions and proper agrotechnical management, the main physical and chemical parameters, including organic matter, of humusogenic technosol (with a layer of FSP) may accelerate the development of grass ecosystems and the process of soil formation. Over time, such soils can approach zonal soils, i.e., podzolized and leached chernozems, in terms of their characteristics.

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