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Influence of Coal Mining Activities on Soil's Agrochemical and Biochemical Properties

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Abstract

Recultivation of technologically disturbed land is an important objective of environmental protection. The study aimed to examine the impact of the coal mining process on the agrochemical and biochemical parameters of soil. Agrochemical and biochemical analysis of soil samples was conducted before and after the mining reclamation stage. The baseline indicators of coal mines indicated that all studied territories needed a full cycle of technologically disturbed land recultivation measures. Before the initial stage of recultivation, the content of carbonate-ion, bicarbonate-ion, copper, lead, zinc, cadmium, and petroleum products in soil samples from the coal mine met the norms and requirements of authorizing documents, and part of the samples from the territory of the Sample 2 coal mine were marked by increased pH and reduced humus content. All samples exceeded the background values of mobile forms of zinc, manganese, copper, lead, nickel, chromium, and cobalt. To effectively improve soil fertility, it is recommended to use biochar, compost, and/or peat and apply organic and inorganic fertilizers. The next stage of research will involve the biological reclamation of technogenically disturbed areas of the coal mines with cultivated and wild plants.

Keywords: Technogenically disturbed land, coal mines, organic matter, heavy metals, petroleum products, soil properties.

1. Introduction

The Earth's population by some estimates is bound to increase by 2.3 billion people in the period from 2009 to 2050, which will require a significant expansion of global food production to meet future food demand (Almanova et al., 2016). The significant increase in atmospheric carbon dioxide levels, primarily caused by various human activities such as the burning of fossil fuels and deforestation, stands as the primary catalyst for the present-day climate change (Kweku et al., 2018; Neverov et al., 2022). Current projections indicate that global temperatures will rise by approximately 1.4-3.1°C once atmospheric CO2 concentrations reach around 670 μmol/mol. The persistent effects of elevated CO2 levels, elevated temperatures, and water scarcity will have a substantial impact on the equilibrium of ecosystem functions, both at regional and global scales (Gamage et al., 2018; Kweku et al., 2018).

Considering that CO_2 is the main substrate for photosynthesis, it can be regarded as the primary driver of global food production (Kimball, 2016). Nearly 90% of plant species are C3 types, not yet photosynthetically saturated under current CO2 levels, suggesting potential increases in photosynthesis and biomass with rising CO2 concentrations (Mikhaylov et al., 2020; Nasiyev, 2013; Nasiyev et al., 2022a, 2022b; Neverov et al., 2022). In these plants, photosynthesis involves ribulose-1,5-bisphosphate carboxylase/oxygenase, which reacts with both CO2 and O2, influencing the efficiency of carbon reduction and oxidation cycles (Chehabeddine & Tvaronavičienė, 2020). The enzyme's effectiveness, often the limiting factor in C3 photosynthesis, is dependent on CO2 and O2 partial pressures, with a higher affinity for CO2. Enhanced carboxylation by ribulose-1,5-bisphosphate carboxylase reduces photorespiration, indirectly boosting the photosynthetic rate. Photorespiration, which occurs when ribulose-1,5-bisphosphate carboxylase oxygenates ribulose-1,5-bisphosphate, leads to a substantial loss of photosynthetically produced energy (Gamage et al., 2018; Moumen et al., 2019). CO2 impacts three key plant physiological processes: photosynthesis, respiration, and water relations (Toebelmann & Wendler, 2020). Thus, gaining insights into the intricate regulation of photosynthesis, respiration, and water utilization, as well as their implications for plant growth in a CO2-enriched environment, presents a distinctive chance to enhance crop yields in the face of a shifting climate (Jacobson et al., 2019; Li, 2021; Peters et al., 2020; Zhang et al., 2019).

The mining industry, including coal mining, has a profound negative impact on the ecosystem, cutting the area of agricultural and other land, the diversity of flora and fauna, as well as the healthy life expectancy of the local population (Baldocchi & Penuelas, 2019). Recultivation of technologically disturbed land is a vital task in environmental protection (Almanova et al., 2016; Wallace-Wells, 2019). The main need for reclamation consists of restoring the value of disturbed lands, improving the ecological conditions of the area, and creating harmonious landscapes that meet ecological, economic, aesthetic, and sanitary-hygienic requirements (Ishtiaq et al., 2018; Kopytov, 2018; Mikhaylov et al., 2020; Mussynov et al., 2014; Nasiyev & Dukeyeva, 2023; Sagdeeva et al., 2019). The Kuznetsk Basin, located primarily in the Kemerovo region of Russia, is one of the world's largest coal mining regions (Kopytov & Shaklein, 2018). Despite the rising global price levels, owing to stable demand for coal, the Kuznetsk Basin remains the leader among Russia's coal mining regions and is the most promising in terms of the most promising in terms of coal reserves and quality, as well as mining infrastructure and engineering conditions. Given the environmental crisis, reclamation zones need to be created on dumps damaged by coal mining. Green plantations can solve problems triggered by the coal industry. Plants can restore disturbed landscapes while reducing carbon footprint (Kopytov, 2018). The present study investigates the possibility of using bioremediation of technogenically disturbed landscapes of coal enterprises and greenhouse gas deposits in the Kuznetsk Basin coal mining area (Kopytov & Kupriyanov, 2019).

This work aimed to study the effect of the coal mining process on soil agrochemical and biochemical parameters.

2. MATERIALS AND METHODS

To carry out the empirical study, we selected several experimental polygons. The selection criteria were the breadth of representation of the region's territory and the possibility of connecting with planned reclamation measures to be implemented on the territory of coal mines. Soil sampling was carried out on four territories. Samples from the coal mine (53°46″ N, 87°44″ E) were designated Samples 1, from the coal mine (54°21″ N, 87°12″ E) – Samples 2, from the coal mine (54°18″ N, 87°22″ E) – Samples 3, and from the coal mine (54°14″ N, 86°46″ E) – Samples 4. As a negative control, we examined soil samples from a forest plot (54°17″ N, 87°15″ E), which were labeled Samples 5.

To collect the samples, five zones were allocated within the studied soil areas, and four parallel soil samples were taken in each zone. Sampling was carried out using the envelope principle: samples were taken from the corners and the center of the area under study (vegetation cover was removed beforehand). The depth of sampling was 0-10 cm, and the mass of sampled material was 0.5-1.0 kg. The selected samples were placed in a 50x50 cm polyethylene bag. Next, the samples were mixed to create a combined sample. Sampling was performed at five different points in the studied land plot. The tool used to collect soil samples was a stainless steel sampling scoop. The storage temperature for the samples was 4±2°C. Before the analysis, organic inclusions (roots, branches, leaves, etc.) and large aggregates were removed from the sampled soil. To obtain an air-dry condition, the soil was spread on clean paper in a layer not exceeding 1.0 cm and dried at room temperature, stirred occasionally. The resulting air-dry mass was ground in a porcelain mortar and sieved (sieve pore area no more than 1 mm^2).

The soil samples whose characteristics were used as negative control (background values) for the study of technologically disturbed lands were taken 10-100 km away from the soil sampling sites of the main study areas. The chosen forest areas were located in the Erunakovskoe and Elovskoe forestries. In terms of administrative and territorial location, they belong to the Novokuznetsk (Krasulinskoe Rural Settlement) and Prokopevskoe (Bolshetaldinskoe Rural Settlement) municipal districts.

The collected samples were numbered, and the place of collection was indicated. The samples were labeled with the location, the date of collection, and the name of the researcher who collected them. Due to the duration of the full cycle of reclamation, the priority was given to coal mines where the initial stage – mining and technical reclamation – had already been completed and biological reclamation of disturbed areas was required.

The study of agrochemical and biochemical indicators of soil samples, including the content of anthropogenic pollutants, was carried out following normative documents. The parameters controlled are described below.

The concentrations of total nitrogen (%), ammonium nitrogen (mg/kg), and nitrate nitrogen (mg/kg) were measured using the Kjeldahl technique (Hu et al., 2022; Lin et al., 2019; Oxukbayeva et al., 2023).

The levels of organic matter (%) and humus were evaluated using the approach described by Tong Zhou et al. (2023) and Gurov et al. (2019). This procedure involves oxidizing organic matter with potassium bromic acid in sulfuric acid, then quantifying the trivalent chromium corresponding to the organic matter using a photoelectrocolorimeter.

Moisture content (%), hygroscopic moisture, hygroscopic moisture coefficient, maximum hygroscopicity, and wilting moisture were determined according to Kayumov and Tukhtaev (2022) and Nielsen (2017). The essence of the method consists of saturating the soil with vaporous moisture and subsequently determining soil moisture.

Soil density, solid phase density, porosity, and water holding capacity were evaluated pycnometerically as described by Bittelli et al. (2021).

Dry residue was measured based on the method by Gallo et al. (2020). The employed method of determining the dry residue is based on estimating the mass loss of a soil sample when dried to a constant mass.

Ash content was identified as proposed by Ismail (2017). The essence of ash content determination methods consists of burning a soil sample and then quantifying the unburned residue.

Soil and water pH were determined using the potentiometric method of hydrolytic acidity measurement (mol/100 g) according to Vago et al. (2010) and Vajová et al. (2021).

Total alkalinity was estimated using the titrimetric method by Trick et al. (2018).

Specific electrical conductivity (mS/cm) was measured using the conductometric method by Taherian (2019).

Identification of cation exchange capacity (mol/100 g) was carried out by complexometric titration according to the method by Jain and Taylor (2023).

Petroleum product content (mg/kg) was measured following the procedure by Vicentini-Polette et al. (2021). This method involves extracting oil products from water samples using an extractant, purifying the extract from polar compounds through chromatography on a column packed with a sorbent, and measuring the intensity of the absorption spectrum of C-H bonds in CH- and CH-groups of aliphatic and alicyclic hydrocarbons and the side chains of aromatic hydrocarbons and CH-groups of the aromatic ring in the infrared (IR) region of the spectrum in the wave number range from 2,700 to 3,150 cm, followed by determining the concentration of oil products by optical density or the spectrum area.

Benzo(a)pyrene content (mg/kg) was measured following the procedure by Koshelkov and Mayorova (2023). The measurement method consists in extracting benz(a)pyrene from soil samples with n-hexane (methylene chloride), concentrating the extract, separating it chromatographically, recording the fluorescence signal using a fluorimetric detector, identifying the benz(a)pyrene peak on the chromatogram by retention time, and calculating the mass concentration of benz(a)pyrene.

Volatile phenols content (mg/kg) was calculated as proposed by Qin et al. (2023). The method determines the mass concentration of phenols in soil that are capable of reacting with 4-aminoantipyrin and forming colored compounds with it.

Formaldehyde content was assessed using the fluorimetric method by Abe et al. (2021).

The content of HCH and its isomers (α-HCH, β-HCH, γ-HCH) and DDT and its metabolites (4,4'-DDDD, 4,4'-DDE, 4,4'-DDDT) were determined using thin layer and gas-liquid chromatography following the procedure by Fabre et al. (2005).

Heavy metal content was measured based on the hydrogen sulfide and thioacetamide methods by Orecchio et al. (2016).

3. RESULTS

The agrochemical and biochemical parameters of soil samples from the studied areas are given in Table 1.

Table 1. Agrochemical and Biochemical Indicators of Soil Samples from the Studied Areas

No.	Indicators determined	TLV GOST 17.5.1.03-86	APC SanPiN 1.2.3685-21	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5 Negative control (background)
1.	Petroleum products, mg/kg	73.6	ns	20.7±6.9	24.8±8.3	32±11	131±44	30±10
2.	Benzo(a)pyrene, mg/kg	0.02	0.02	<0.005	<0.005	0.0098±0.0032	<0.005	<0.005
3.	Volatile phenols, mg/kg	ns	ns	<0.05	<0.05	<0.05	<0.05	0.084±0.037
4.	HCH and its isomers, μg/kg							
	□-HCH	ns	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	□-HCH	ns	0.1	<0.1	<0.1	<0.1	<0.1	0.182±0.054
	□-HCH	ns	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5.	DDT and its metabolites, μg/kg							
	4,4'-DDT	ns	ns	<0.1	<0.1	<0.1	<0.1	<0.1
	4,4'-DDD	ns	ns	<0.1	<0.1	<0.1	<0.1	<0.1
	4,4'-DDE	ns	ns	<0.1	<0.1	<0.1	<0.1	<0.1
6.	Salt extract pH	ns	ns	5.5±0.1	6.9±0.1	7.6±0.1	7.3±0.1	6.2±0.1
7.	Water extract pH	5.5-8.4*	ns	6.9±0.1	7.7±0.1	8.5±0.1	8.5±0.1	7.0±0.1

8.	Total nitrogen, %	ns	ns	0.0244±0.0056	0.182±0.015	0.124±0.011	0.120±0.011	0.616±0.039
9.	Organic matter, %	(by humus) >1.0**	ns	0.80±0.13	4.00±0.50	4.02±0.51	2.49±0.42	9.35±0.79
10.	Moisture, %	ns	ns	9.17±0.77	10.04±0.84	5.54±0.47	8.32±0.70	15.2±1.3
11.	Nitrate nitrogen, mg/kg	ns	ns	3.06±0.82	30.2±5.6	10.6±2.0	66±12	8.2±1.5
12.	Ammonium nitrogen, mg/kg	ns	ns	<20	<20	<20	26.3±2.9	<20
13.	Cation exchange capacity, mmol/100 g	ns	ns	36.1±6.4	36.1±6.4	60±11	52.2±9.2	50.2±8.8
14.	Mobile phosphorous according to Chirikov in terms of P_2O_5, mg/kg	ns	ns	41±12	14.1±4.1	34±10	52±15	27.1±8.0
15.	Mobile potassium according to Chirikov in terms of K_2O, mg/kg	ns	ns	81±23	112±31	126±35	104±29	181±51
16.	Phosphorus (gross content) in terms of P_2O_5, %	ns	ns	0.151±0.044	0.151±0.044	0.136±0.040	0.114±0.034	0.210±0.062
17.	Potassium (gross content) in terms of K_2O, %	ns	ns	1.95±0.65	2.00±0.67	2.25±0.75	2.03±0.68	1.68±0.57
18.	Specific electrical conductivity, mS/cm	ns	ns	0.041±0.003	0.202±0.013	0.104±0.007	0.123±0.008	0.134±0.008
19.	Sum of absorbed bases, mmol/100 g	ns	ns	32.1±4.0	21.3±2.7	47.4±6.0	49.5±6.2	43.5±5.5
20.	Hydrolytic acidity, mmol/100 g	ns	ns	1.23±0.12	0.910±0.092	0.230±0.023	0.260±0.026	1.70±0.17
15.	Mobile potassium according to Chirikov in terms of K_2O, mg/kg	ns	ns	81±23	112±31	126±35	104±29	181±51
16.	Phosphorus (gross content) in terms of P_2O_5, %	ns	ns	0.151±0.044	0.151±0.044	0.136±0.040	0.114±0.034	0.210±0.062
17.	Potassium (gross content) in terms of K_2O, %	ns	ns	1.95±0.65	2.00±0.67	2.25±0.75	2.03±0.68	1.68±0.57
18.	Specific electrical conductivity, mS/cm	ns	ns	0.041±0.003	0.202±0.013	0.104±0.007	0.123±0.008	0.134±0.008
19.	Sum of absorbed bases, mmol/100 g	ns	ns	32.1±4.0	21.3±2.7	47.4±6.0	49.5±6.2	43.5±5.5
20.	Hydrolytic acidity, mmol/100 g	ns	ns	1.23±0.12	0.910±0.092	0.230±0.023	0.260±0.026	1.70±0.17
				Gross content				
21.	Cadmium, mg/kg acidic (loamy and clayey), pH KCl<5.5	1.0	1.0	0.35±0.15	-	-	-	0.42±0.18
	close to neutral, neutral (loamy and clayey), pH KCl>5.5	2.0	2.0	-	0.35±0.15	0.26±0.11	0.33±0.14	
22.	Copper, mg/kg acidic (loamy and clayey), pH KCl<5.5	66.0	66.0	18.2±3.1	-	-	-	16.9±2.8
	close to neutral, neutral (loamy and clayey), pH KCl>5.5	132.0	132.0	-	17.7±3.0	18.1±3.0	16.6±2.8	
23.	Arsenic, mg/kg	2.0	-	-	-	-	-	-
	acidic (loamy and clayey), pH KCl<5.5	5.0	5.0	5.3±2.2				5.2±2.2
	close to neutral, neutral (loamy	10.0	10.0	-	4.6±1.9	6.0±2.5	5.1±2.1	

	and clayey), pH KCl>5.5							
24.	Nickel, mg/kg							
	acidic (loamy and clayey), pH KCl<5.5	40.0	40.0	28.0±8.2	-	-	-	
	close to neutral, neutral (loamy and clayey), pH KCl>5.5	80.0	80.0	-	24.3±7.1	20.1±5.9	22.4±6.6	25.8±7.6
25.	Lead, mg/kg							
	acidic (loamy and clayey), pH KCl<5.5	ns	65.0	17.9±3.8	-	-	-	
	close to neutral, neutral (loamy and clayey), pH KCl>5.5	ns	130.0	-	20.0±4.2	31.6±6.6	22.4±4.7	20.7±4.4
26.	Zink, mg/kg							
	acidic (loamy and clayey), pH KCl<5.5	ns	110.0	48.1±8.1	-	-	-	
	close to neutral, neutral (loamy and clayey), pH KCl>5.5	ns	220.0	-	51.2±8.6	55.2±9.3	48.2±8.1	60±10
27.	Mercury, mg/kg	ns	2.1	0.0127±0.0048	0.061±0.023	0.069±0.026	0.027±0.010	0.032±0.012
28.	Cobalt, mg/kg	ns	ns	20.8±7.0	21.2±7.1	18.6±6.3	21.6±7.2	19.8±6.6
29.	Manganese, mg/kg	1,500.0	1,500.0	680±230	860±290	670±220	860±290	910±310
30.	Chrome, mg/kg	ns	ns	74±19	66±17	42±11	61±15	71±18

ns – not standardized. ***5.5-8.2** for humus soil horizons; **5.5-8.4** for potentially and marginally suitable soils (except for unsuitability by chemical composition); **3.5-5.5** for soils with marginally suitable chemical composition – acidic soils; **5.5-9.0** for soils with marginally suitable chemical composition (containing easily soluble salts, gypsum, carbonates); **3.5-9.0** for soils with marginally suitable physical composition; **up to 3.5** for soils unsuitable by chemical composition (sulfides); **above 6.5** for unsuitable soils (easily soluble salts, gypsum, carbonates). **By humus: More than 1 for forest and semi-desert zones; more than 2 for steppe and forest-steppe zones – for suitable soils; for others – ns.

The content of petroleum products in Samples 1-3 was below the threshold limit value (TLV) (73.6 mg/kg) and the background value (30 mg/kg), yet in Sample 4, their content exceeded the indicators by more than four times (131 mg/kg). The content of benz(a)pyrene, volatile phenols, HCH and its isomers, and DDT and its metabolites did not exceed the TLV, approximate permissible concentration (APC), or background values (negative control) in any of the soil samples.

Soil samples from two territories (Sample 1 and Sample 4) showed alkaline values of pH (water) and pH (salt) indices in comparison with the negative control. Organic matter content in terms of humus was two or more times lower in the studied samples compared to the background value (9.35%). The least amount of organic matter was found in Sample 1 (0.8%).

The gross content of copper, nickel, lead, cobalt, chrome, zinc, and manganese did not exceed the TLV/APC. However, in all samples except Sample 4, the content of these metals was higher than the background (16.9 mg/kg) by approximately 1.0 mg/kg. Arsenic content tended to be higher than the TLV/APC, which was apparent in Sample 1 (5.3 mg/kg). Sample 3 also demonstrated arsenic content above the background level (6.0 mg/kg). Nickel content higher than the background value was found in Sample 1 (28.0 mg/kg). For lead, exceedance of the background value was observed in Samples 3 (31.6 mg/kg) and 4 (22.4 mg/kg). In Samples 1, 2, and 4, the content of cobalt was higher than the background 1-2 units on average. Sample 1 (74 mg/kg) exceeded the background value for chromium content. Sample 3 (6.1 mg/kg) was almost 2 times higher than the background value in zinc content. Manganese content in Samples 2 (61 mg/kg), 3 (62 mg/kg), and 4 (24.9 mg/kg) was higher than the background value by 3.7, 3.6, and 1.5 times, respectively. Copper content did not go beyond the TLV in any of the samples. However, all samples surpassed the background by the content of volatile zinc, manganese, copper, lead, nickel, chromium, and cobalt (Samples 1, 2, and 4).

Except for petroleum products and arsenic content, soil samples from some territories demonstrated no exceedances of TLV/APC indicators by the studied parameters. This observation confirms that restoration activities had been conducted in the studied areas previously. Samples from the Sample 2, Sample 3 and Sample 4 contained more than 30 mg/kg nitrate nitrogen, which will later be used by plants for their growth.

Mobile phosphorus content in the soil samples ranged from 14 to 52 mg/kg. In most areas, the content exceeded that of the negative control. However, most often, phosphorus is found in the soils of disturbed areas in a form that makes it inaccessible to plants, so it is not consumed and accumulates in the soil layers, causing pollution.

The soil samples collected from the Sample 1 before recultivation activities met the standards and requirements of authorizing documents by carbonate ion, bicarbonate ion, copper, lead, zinc, cadmium, and petroleum products content. Part of the samples from Sample 2 were marked by increased pH and reduced humus content. Three out of four plots had a pH reaching 7.5-8.4 and higher. Soil samples from the Sample 3 were distinguished by a weakly acidic reaction of the soil solution medium (pH 5.5-6.2), contained insufficient amounts of nutrient elements for plants, and were characterized as clayey and loamy in terms of granulometric composition. The studied soil samples from the Sample 1 were high in nickel (44.3±13.1 mg/kg). High cadmium and arsenic content was detected in samples from Sample 2. Finally, the technogenic soils of the studied territories (the Sample 4), as compared to background content in the region's soils, had an increased gross content of heavy metals: arsenic levels were 1.2-1.8 times higher. Given this, the studied areas were classified as hazardous soil types not suitable for biological recultivation.

4. DISCUSSION

Nitrogen accumulated in soils in different forms can be transformed by microorganisms, the activity of which is extremely limited in the disturbed territories of coal-mining enterprises. Nitrogen accumulation in the disturbed areas of coal mining enterprises occurs, among other things, during the oxidation of coal or coal dust over time with the involvement of certain microorganisms in these areas. Ammonium/nitrate nitrogen content indicates that the soils of all the studied territories were virtually not cultivated and had been undisturbed for some time.

Hydrolytic acidity (mmol/100 g) and the sum of consumed bases (mmol/100 g) were used to determine soil saturation, which indicated the need for liming. A value under 50% suggests a strong need for liming, 50-70% – average necessity, 70-80% – a low need, and a level higher than 80% shows that the soil does not require liming. The level of saturation of soil samples from the studied areas exceeded 90%, suggesting that there was no need for preliminary liming (before planting). In terms of all other micro- and micro-elements needed by plants, all soil samples, including negative control, showed low content levels. This points to the need to introduce mineral fertilizers, as well as organic fertilizers, to increase organic matter (humus) content in the soil layers of technologically disturbed areas as part of phytoremediation measures. Low quantities (<0.015%) of magnesium ions, calcium ions, sodium ions, chloride ions, sulfate ions, carbonate ions, and bicarbonate ions (%, water extract) indicated the low salinity of soils in the studied areas.

Except for petroleum products, soil samples from the studied territories did not surpass the TLV/APC levels by the studied parameters, which confirms that restoration activities had been conducted in the studied areas before. This conclusion is also supported by the accumulation of various forms of nitrogen in the soils, which can be transformed by microorganisms whose life is extremely limited on the disturbed territories of coal mining enterprises. Nitrogen accumulation in the disturbed areas of coal mining enterprises occurs, among other things, during the oxidation of coal or coal dust over time with the involvement of certain microorganisms in these areas. The content of ammonium/nitrate nitrogen suggests that the soils of all these territories were practically not cultivated and had recently been undisturbed.

Based on the degree of pollution and other characteristics, soils are categorized according to their suitability for biological reclamation as suitable, marginally suitable, and unsuitable soils. Among other types of soil, non-saline loams and heavy and medium loams are referred to as potentially fertile soils, the low natural fertility of which owes to the lack of nutrients, especially nitrogen and phosphorus (Chibrik, 2002). For this reason, soils of all the studied areas can be subjected to bioremediation.

In the course of the study, we analyzed studies by leading researchers investigating the impact of the coal mining process on the agrochemical and biochemical parameters of soils (Guo et al., 2018; Li et al., 2020; Yakovchenko et al., 2017, 2021).

A study by Yakovchenko et al. (2017) reports the results of analyzing the agrochemical characteristics of soils of an operating coal mine of Shakhta No. 12 LLC in the Kemerovo region, including granulometric composition, humus, phosphorus, and potassium content, heavy metal content, and soil extract reaction. The analysis indicates that the amount of humus in the upper soil layer amounts to 3.1-6.2% and drops sharply as depth increases. Total phosphorous content is also low at 0.13% and decreases dramatically with depth. Total potassium content is average throughout the profile, and nitrogen content at all sites varies from 0.12 to 0.48%, which is undoubtedly associated with the natural climatic location of the sites.

The study's findings indicate that the soil solution's pH varies from slightly to strongly acidic, particularly in the lower layers. The concentration of labile heavy metals in the soil samples remains below the threshold limit value (TLV) in mg/kg. Although the topsoil at the coal mine sites examined is fertile, it cannot be conserved or relocated due to the extensive forest cover, including ravines and numerous trees damaged by wind, across the entire area under study (Yakovchenko et al., 2017).

Xiao-ming Guo et al.'s research (Guo et al., 2018) highlights the crucial role of quantitatively assessing coal mining-induced subsidence effects on soil quality to develop sustainable local agricultural strategies. This study aimed to use principal component analysis to determine the impact of slope position, a result of coal mining activities, on soil quality. Soil samples from five coal dump locations—top, upper, middle, lower, and bottom slopes—and from adjacent, unplanted agricultural land (as a control) were analyzed for 21 physical, chemical, and biological parameters. Key indicators included urease, polyphenol oxidase, and phosphatase enzymatic activities, actinomycetes count, bulk density, salinity, and organic matter content. The soil quality index (SQI) was highest at the bottom and lower slopes, followed by agricultural land, top, middle, and upper slopes. Interestingly, despite high SQI values, the bottom and lower slopes had lower yields, suggesting that factors not covered in this study might more significantly affect crop productivity. Overall, the study found that slope position due to coal mining substantially affects soil quality and agricultural output (Guo et al., 2018).

In Yakovchenko et al.'s study (2021), the examined sites at the Yerunakovskoe deposit, classified as group E in the Kuznetsk-Alatau high-mountain soil region within the black taiga zone, feature deep soddy and thin podzolic heavy loam soils. The fertile layer of these soils' ranges from 18 to 26 cm with a humus content of 5-8%, and the lower horizons vary from slightly to strongly acidic. The study notes that utilizing these lower horizons, with lower agronomic value, requires significant financial investments (Yakovchenko et al., 2021).

Li et al. (2020) highlight the importance of revegetation and soil restoration in ecological rehabilitation at surface coal mining sites. Their study assessed ecological stability as a key measure of restoration success at three coal mines: Wulanhada (WLHD), Liulingou (LLG), and Jinzhengtai (JZT). Over time, WLHD and LLG showed increased levels of organic matter, total nitrogen, available nitrogen, and available potassium during land recovery. However, JZT experienced an initial increase in these nutrients, followed by a slight decrease. A redundancy analysis indicated a positive correlation between soil properties (moisture, organic matter, total nitrogen, available potassium) and plant species diversity across all sites, while soil pH and bulk density were negatively correlated with diversity (Li et al., 2020).

5. CONCLUSIONS

Before the initial stage of recultivation, soil samples from the Sample 1 were characterized by increased pH and elevated humus content. Soil samples from the Sample 3 showed a slightly acidic reaction of the soil solution medium (pH 5.5-6.2). The samples from the Sample 1 contained a large amount of nickel (44.3±13.1 mg/kg). High cadmium and arsenic content were observed in soil Sample 2. Gross heavy metal content in the soils of the Sample 3 did not exceed the TLV/APC set for clayey and loamy compositions. Compared to background content in the region's soils, technogenic soils of the studied territories (Sample 4) had an increased gross content of heavy metals: arsenic levels were 1.2-1.8 times higher. The presence of radionuclides in the samples precludes the use of these territories for agricultural needs until the completion of the full recovery stage. Soils of all the other studied territories are referred based on the results of the study to non-saline loams (heavy or medium), the natural fertility of which is reduced due to the lack of nutrients. The study found no need for measures of the remediation stage of mining reclamation, as all territories were deemed suitable for the next stage – biological recultivation. Correction of soil indicators that had not reached the required values should be achieved by selecting appropriate planting material. The next stage of research will involve the biological reclamation of the anthropogenically disturbed areas of selected coal mines with cultivated and wild plants.

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