AgroLife Scientific Journal - Volume 13, Number 2, 2024
ISSN 2285-5718; ISSN CD-ROM 2285-5726; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

QUALITY OF THE SOILS ON DEGRADED MINING LANDS AND POSSIBILITIES OF RESTORING THEIR FERTILITY - CASE STUDY: ROVINARI COAL BASIN

Izabela-Maria APOSTU, Florin FAUR, Maria LAZĂR, Eugen TRAISTĂ

University of Petroșani, 20 University Street, Petroșani, Romania

Corresponding author email: izabelaapostu@upet.ro

Abstract

Top soil is a valuable and vital resource. It is highly sensitive to human actions that may cause its quantitative and qualitative deterioration and destruction. The rate of soil destruction is significantly higher than that of restoration, and for this reason it is important to minimize the surfaces of land affected by mining. In the case of degraded surfaces, in order to return to the economic or ecological circuit, interventions are required on the pedogenesis process, which naturally is a long-lasting one. This research aims to improve soil quality on mining dumps by carrying out pot experiments considering soil substitutes based on mixtures of industrial waste, household, and stable biodegradables and using soil improver plant species. Individual soil quality indexes were described and a methodology was proposed and applied to assess the aggregate anthropogenic soil quality index. The analyses indicated that rocks as sands, clays, dusts, which are the main constituents of some waste dumps, represent a good base of inorganic matter necessary in the pedogenesis process, and with interventions, and, if needed, fertilization, their properties can be improved.

Key words*: waste dumps, anthropogenic soils, pedogenesis, quality index, methodology, evolution.*

INTRODUCTION

The awareness that the soil is a valuable resource, quantitatively reduced, and difficult to regenerate, stimulated the implementation of managerial practices to ensure its long-term protection, conservation, and improvement.
The quality of the soil is described by the chemical, physical and biological characteristics that allow it to perform ecological functions (maintaining the ecological balance at the local, regional, global level, supporting biological activity, storage, regulating the flow of air - water - nutrients, filtration, detoxification), productive (supporting plant development), and protective (Cherubin et al., 2016; Bhattacharyya et al., 2017; Lazăr, 2010; Cojocaru & Abramov, 2023).
A typical soil is made up of approximately 45% inorganic material of mineral origin (sand, dust, clay, and sometimes fine gravel), 5% organic matter; 25% water, and 25% air (Weil & Brady, 2024; Jury & Horton, 2004; Eldor & Clark, 2013).
Waste rocks resulting from lignite mining activity, that contain unharmful elements and have acceptable structure and properties which can be improved, represent the inorganic base needed in soil formation process. Organic matter is very important for a healthy and fertile soil improving the physical, chemical and biological properties of the soil (Bosch-Serra et al., 2023; IUSS, 2022; Buscot, 2023; Dumitru et al., 2016; da Silva et al., 2023; Schulte et al., 2014; Gerke, 2022; Khalidy et al., 2022).
Soil quality can be estimated indirectly by measuring the physical, chemical and biological properties of the soil that serve as quality indicators/indices. Individually, these indices may not provide clear indications regarding the state of soil quality, therefore a combination of properties taken into analysis may reflect its actual state (Schulte et al., 2014).
Evaluating the soil quality indices, whether they are naturally or anthropically degraded soils, it is possible to establish their sensitivity level, which allows for improving their resilience, i.e. the ability of the soil to return closer to the initial quality state through appropriate management practices (Bhattacharyya et al., 2017; Lazăr, 2010; Brejda et al., 2000; Diack & Scott, 2001; Chaudhry et al., 2024).

Evaluating soil quality is an essential component in managing this resource. It assesses and monitors how the soil functions at a given moment and how it evolves in the long term.

In the Rovinari mining basin, the soil is selectively extracted, but it is not enough for revegetation, so it is necessary to analyze the rocks in the intercalations from the point of view of their ability to represent, under certain conditions, soil substitutes.

Supporting soil recovery using local resources is considered to be an optimal solution. It is recommended to establish so-called green crops to be incorporated into the soil as green fertilizers. There are a number of plants recommended as green manures, such as clover, grass, alfalfa, green peas, etc. Among the main characteristics of these plants are: high speed of installation; high degree of germination; fixing nitrogen into the soil (through symbiosis with nitrogen-fixing microorganisms); the production of a plant mass as rich as possible (high productivity); high thread density; low sensitivity; resistance to drought, temperatures variations; increased regeneration capacity after cutting/mowing (case of clover, alfalfa and grass); the vegetation period (of the order of months) that allows the analysis and observations necessary for the proposed research; the appropriate sowing and germination period; efficiency on soils poor in organic matter; improving the physico-chemical properties of the soil (Singer, 2015; Peñaranda, 2020).

The study was carried out at the level of the Rovinari mining basin, located in Gorj County (Romania). The component mining perimeters (Figure 1) were/are located on both sides of the Jiu River, in the meadow area, but also in the hilly areas of the region. The main activities carried out in the Rovinari basin are represented by the excavation of lignite with its transport in the coal deposits and the excavation of waste rocks with their transport into internal or external dumps.

Over time, 12 open-pits were put into operation in the Rovinari mining basin, occupying an area of 14000 ha (56% being occupied by internal and external dumps) (Fodor & Lazăr, 2006).

During the field trips and proper documentation, the research team obtained information regarding 18 internal and external dumps that belong to the Rovinari basin regarding the current state of the dumps, the characteristics of the sterile rocks, the main plant species (herbaceous species, shrubs and trees) developed on these lands, etc. Of the 18 dumps, only 6 are still active. The other 12 are inactive as a result of the cessation of exploitation activity of which 7 are ecologized and 5 are partially ecologized.

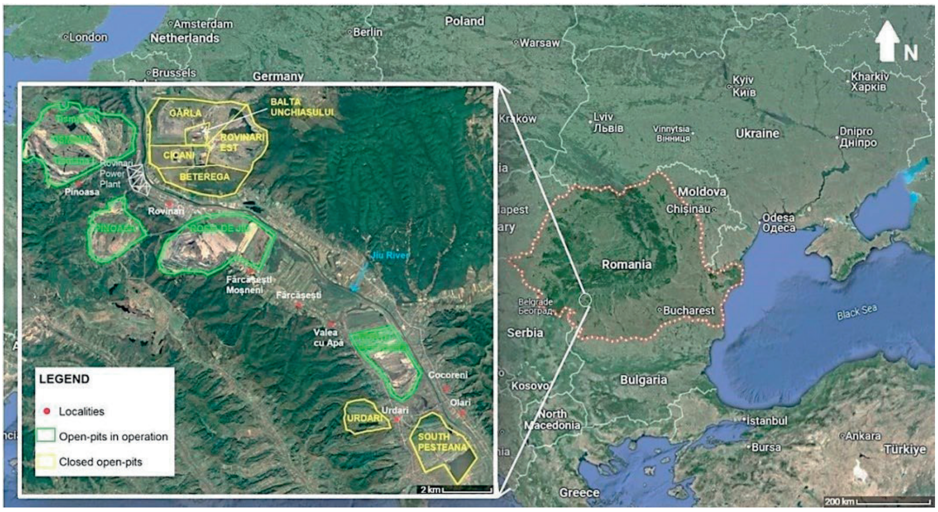

Figure 1. Rovinari mining basin - the situation plan

MATERIALS AND METHODS

The research assumed in the first phase the realization of pot experiments. To carry out the pot experiments, several stages were completed: choosing the location, initial sampling and testing stage, installation and preparation of vegetation pots, monitoring and final sampling and testing stage.

Considering the surface of the Rovinari mining basin, but also the lithological constitution of the region, the physical, chemical, and pedological characteristics of the waste rocks, the similar mining/dumping methods throughout the basin, it was chosen to carry out a case study on the Peșteana Nord mining perimeter regarding the possibilities of accelerating the pedogenesis process on the related internal dump, considering that the results obtained can be easily extrapolated at least at the level of this basin (ISPE, 2012).

A plot of approximately 50 ha was chosen and five samples were taken (PH1 - PH5; the plot corresponds to the upper platform of second step of the internal dump of the Peșteana Nord open-pit) (Figure 2). The sampling depth was set at a maximum of 20 cm. In order to obtain a representative sample from the dump ($PM_{1–4}$), the samples taken (PH1 - PH5) were subjected to mechanized mixing using a concrete mixer, resulting a proper aeration of the material, this being very important to stimulate the fixation and development of the roots.

Also, samples of coaly marl (PM_5) and sandy clay (PM_6) were taken from the sterile intercalations from the in situ slopes and they were used as substrate - blank/control samples for making comparisons within the experiment.

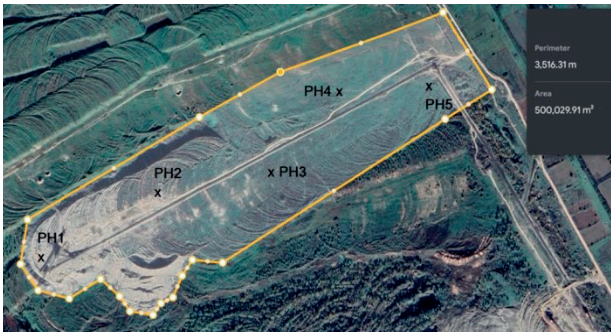

Figure 2. Location of plot and sampling points on the dump

In the studied area, instead of the original soils (existing before mining), lithological materials with various characteristics remained that represent the basis of anthropogenic protosols (Entiantrosols). The volume of soil that can be used by plant roots (edaphic volume) is sufficient for the development of the roots, but it lacks the main fertility characteristics.

The common characteristics of anthropogenic soils in Peșteana Nord perimeter are (ISPE, 2012; Sung et al., 2017; Faur et al., 2019; Predoiu et al., 2023; Lazar et al., 2023):

- reduced cationic exchange capacity, the sterile material being prone to acidification;
- inert-non-dangerous materials;
- it does not undergo any disintegration or any other significant change that may cause a negative effect on the environment or harm human health;
- normal load classes in terms of heavy metal, fluorine, cyanide, phenol, sulfate and hydrocarbon content;
- microbiological activity is low as a result of the low number of individuals, which means that the pedogenesis process will have a much longer duration than under normal conditions;
- variation of moisture depending on the meteorological and climatic conditions.

Carrying out a comparative analysis of the original soils and anthropogenic soils, it was found that macronutrients are not only present in the anthropogenic soils, but are found in even greater quantities compared to the case of the original soils, this being explained by the fact that there are reserves of nutrients and nutrient input from the deep layers (Fodor & Smeu, 2013).

The sterile samples collected from Peșteana Nord open-pit and internal waste dump, which in fact constitute the three blank sample from the experiment ($PM_{1–4}$, PM_5, PM_6), have the following characteristics:

- From physical point of view, the sterile material is composed of different mixtures of clays, dusts, sands, and gravel elements, with variable volumetric weights between 17.4 and 20.3 kN/m^3, specific weight of approx. 26 kN/m^3, natural moisture between 23-29%, and porosity of 40-60%. These values vary depending on the external influences (season, precipitation, overloads, root development, etc.) and can be easily maintained by the occasional application of aeration, watering/irrigation procedures, with the reduction as much as possible of the use of heavy machinery on the land surface;
- From biological point of view, microorganisms and mesoorganisms were

identified on the dump, such as bacteria, fungi, algae, amoeba, ants, spiders. Macroorganisms were not identified on the dump as a result of the noise from the mining machines working in continuous flow.

For the installation and preparation of vegetation pots, trapezoidal light gray concrete pots (length 30 cm, width 15 cm, depth 15 cm, area at the top 187.5 cm^2, volume 2.81 dm^3) were used ensuring permeability for air and water, being durable, resistant, and reusable.

Based on the literature (Cormen et al., 2022; MMGA, 2005) and the plant properties to be soil improvers, the following species (S) were chosen:

- S1 = green peas (*Pisum sativum*);
- S2 = 50% red clover (*Trifolium pratense*) + 50% grass (universal grass made from a mixture of seeds: 50% *Lolium perenne*, 30% *Festuca rubra*, 20% *Lolium multiflorum*);
- S3 = 50% alfalfa (or lucerne; *Medicago sativa*) + 50% grass (same universal grass).

To create the recipes/mixtures for soil (R), we used three types of waste, some of which represent an inorganic base (industrial waste), others organic (biodegradable waste), and, in addition, to make some comparisons, it was used an organic fertilizer. More precisely:

- industrial waste: sterile rock from waste dumps related to lignite open-pits representing the base of inorganic matter. The solification rock within the Peșteana mining perimeter is the parental material represented by the loose and soft sedimentary rocks;
- biodegradable household waste: compost enriched with active carbon (bio-coal). Bio-coal is an organic fertilizer carrying nutrients and microorganisms, but also a biological fertilizer for soil conditioning, recommended for all soil types. Its application facilitates the incorporation of manure into the soil also reducing nitrogen and methane emmisions;
- biodegradable barn waste: cow manure (natural organic fertilizer);
- mineral fertilizer composed of macroelements N - P - K (13% - 5% - 24%) and microelements (Fe, S, MgO, Mn, Zn, Cu, B). It has the advantage of being a slow-release fertilizer, which contributes to the improvement of the soil structure, the healthy development of the roots, the increase of the plant's resistance to the weather, water retention in the soil, etc.

Starting from the theoretical composition of a typical soil, the soil recipes (R) were proposed as follows:

- R1 = 100% sterile material (blank sample PM_{1-4});
- R2 = 90% sterile material (blank sample PM_{1-4}) + 5% compost + 5% manure;
- R3 = 85% sterile material (blank sample PM_{1-4}) + 10% compost + 5% manure;
- R4 = 85 % sterile material (blank sample PM_{1-4}) + 10% compost + 5% manure + fertilizer;
- R5 = 100% sterile material from intercalations (sandy clay; blank sample PM_5);
- R6 = 100% sterile material from intercalations (coaly marl; blank sample PM_6).

In this point the mixing was done manually. All the materials being prepared, the stage of installation and preparation of the pots, including sowing, was completed (Figure 3).

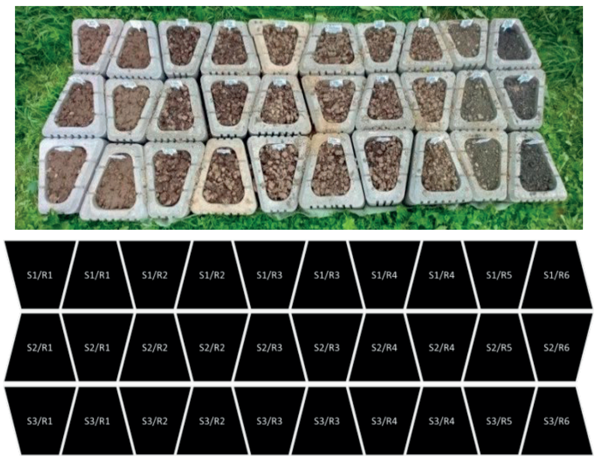

Figure 3. Completing the sowing stage and labeling the pots according to the substrate and species used (S - plant species; R - recipes/soil mixtures)

The watering rate was established in accordance to the weather conditions (ANM, 2023). The watering rate was variable (between 8 and 24 l/pots surface/day). Daily addition ensured the water requirement in the periods without precipitation.

During the experiment, moisture, soil pH, and degree of illumination were measured. The three parameters were monitored to be able to follow the current state of the soil, thus knowing the need for intervention to obtain satisfactory yields. In Figure 4, the evolution of the plants can be seen.

Figure 4. The evolution of the plants

The collection of samples (both plants and substrates) from the vegetation pots was carried out on day 94 (D94), when it was considered that the plants were sufficiently well developed. The samples were collected in plastic bags to preserve the natural moisture of the substrate used and the vegetation itself until the analyses were carried out in the laboratories of the University of Petroșani.

Phenological observations were carried out during and after the experimental stage. Table 1 show data on plant size (length, width, height, number of seedlings, plant mass in wet/natural and dry state) determined after the harvesting stage.

In Figure 5 (left), the share of the dry mass in the total mass of the plants is represented graphically, being important in the analysis as it provides indications regarding the possible increase of the organic matter quantity in the anthropogenic soil.

Dry matter (D.M.) is determined by drying the sample in an oven at 105°C for 12-24 hours. It represents the mass loss of the samples from the natural/wet state and includes both nutrients and ash (Al-Arif et al., 2017).

In general, in the case of peas, the D.M. of the plant represented between 33-50% of its total mass in the wet state. D.M. of the other plants represented approximately 24-35% of the mass of the plants in the wet state. The difference represents the amount of water contained in the mass of the plant, so while in peas approximately 2/3-1/2 represents water, in grass + red clover and grass + alfalfa the water represents more, approx. 2/3-3/4 of the mass of the plant.

Knowing the D.M. mass obtained on each substrate used in the experiment, the mass of the D.M. per square meter was determined (Figure 5, right).

Table 1. Average plant height and weight data

Soil recipes		R1	R2	R3	R4	R5	R6
green peas							
Average height of the plant, cm		> 50	> 50	> 50	> 50	> 50	9.5
Maximum root length, cm		16.5	17.5	37	20.5	20	12
Number of pods/pot		32	20	56	31	108	0
Pod lenght, cm		3-7	2.5-7.5	3-8	2-6.5	2.5-7	-
Pod width, cm		1-1.5	1-1.5	1-1.5	1-1.3	0.9-1.3	-
Plant mass	wet, g	91.01	65.76	105.78	70.13	180.03	15
	dry, g	32.99	31.85	45.89	34.2	59.01	10
	100·dry/wet, %	36.25	48.43	43.38	48.77	32.78	66.67*
grass + red clover							
Maximum height of the plant, cm		81	88	87	70	72	76
Maximum root length, cm		36.5	31	30	30.5	30	32
Total lenght, cm		117.5	119	117	100.5	102	108
Plant mass	wet, g	525.5	358	215.5	357.5	615	651
	dry, g	127	93.75	53.25	117.25	166.5	214.5
	100·dry/wet, %	24.17	26.19	24.71	32.80	27.07	32.95
grass + alfalfa							
Maximum height of the plant, cm		75.5	77	76	67.5	82	76
Maximum root length, cm		36	24	26	27.5	27	34
Total lenght, cm		111.5	101	102	95	109	110
Plant mass	wet, g	413	320	281	530	657	752
	dry, g	98.75	83	65.75	154.5	206.5	263.5
	100·dry/wet, %	23.91	25.94	23.40	29.15	31.43	35.04

*the value cannot be taken into account considering that the peas did not develop well in R6.

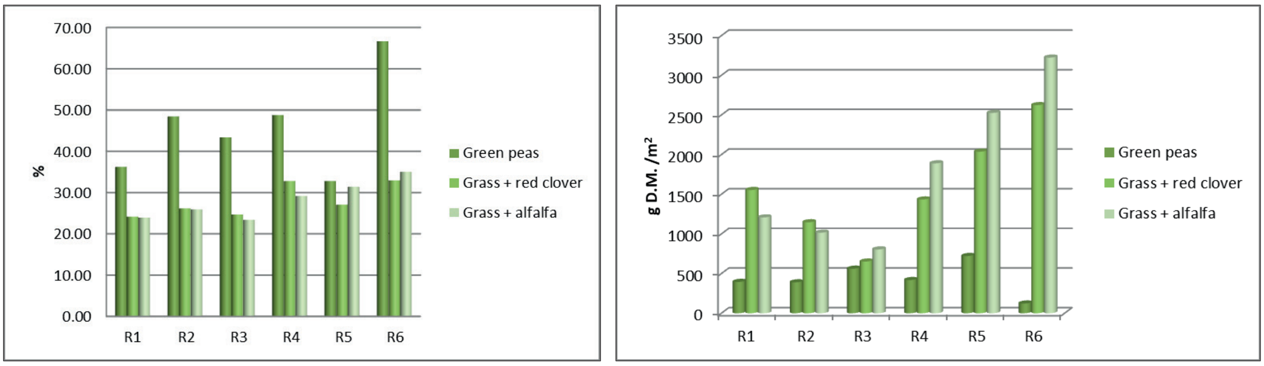

Figure 5. The share of the dry mass in the total mass of the plants - left; D.M. mass per square meter - right

Analyzing the graph, the results indicate that peas provide the largest amounts of D.M. in the case of substrates R4 (consisting of 85% sterile, 10% compost, 5% manure) and R5 (100% sandy clay from intercalations). Grass mixed with red clover and grass mixed with alfalfa provided large amounts of D.M. in R1 (100% sterile material) but especially in the waste rocks directly from the intercalations (R5 - sandy clay and R6 - coaly marl). In the case of R4, herbaceous species have the best results, but comparing it with the R3 recipe, it can be seen that the difference in terms of the substrate is only in the fertilizer added in R4, which explains the significant increase in the D.M. mass.

The extrapolation on a large scale (of the order of hectares) of the results obtained in pot experiments is not justified, as intermediate steps such as in situ experiments are necessary.

In general, sterile substrates gave good and very good results, supporting the growth of the chosen species and achieving high productivity. The results indicate that these herbaceous species can be used to recultivate sterile material deposits (with the characteristics of those presented in this paper) to obtain a plant mass that can contribute to their enrichment with organic matter and support the pedogenesis processes. These results can only be considered as partial indications. Chemical analyses are the ones that complement, confirm, or deny these partial results and based on which certain results can be presented.

Also, before and during the process of soil formation in the experiment, physical, chemical, and biological analyses (which basically defines the pedological characteristics) were carried out. All the samples, including blank samples and samples of soil mixture (after harvesting stage), were subjected to these type of analyses and the results showed the following:

- the manure, compost, and fertilizer added to soil mixture do not influence the granulometric composition and have beneficial effects on the other characteristics, maintaining the appropriate porosity and moisture;
- from biological point of view, and in the case of pots we can not speak about large organisms. In the field experiments that will follow, the presence of macro-organisms will be able to be studied;
- from chemical point of view, the following were observed: the increase in pH to a slightly alkaline environment, favorable conditions for the good development of alfalfa and clover, the decrease in salinity as a result of the leaching processes, the increase in the amount of organic matter, the presence and maintenance of optimal amounts of calcium carbonate (5-9%) which presents the acidification of the soil (and the transfer of trace elements from the soil to the plants, if the case - in our experiments, as mentioned before in the paper, the trace elements content its well below the admitted levels), the nitrogen decreased considerably due to the consumption by the plants in the first experimental stage, of leaching, or, possibly, as a result of the removal of the bearing nodules of nitrogen fixing bacteria from the analysed substrates, phosphorus and potassium increased due to the input from compost, manure, fertilizers, and even coal fragments, and calcium and magnesium decreased

- quantitatively as a result of the leaching processes. Through appropriate interventions, all chemical characteristics can be brought to optimal levels;
- from pedological point of view, the base material (the material from the waste dump) is devoid of humus, generally have a clayey-sandy texture, a glomerular structure, hardly permeable with very poor aeration as a result of the pressure determined by the heavy machines on the dump surface or as a result of the lithological pressure manifested on the sterile layers, moderately cohesive, with a pH reaction from weakly acidic to weakly alkaline, totally free of soluble salts and with traces of calcium carbonate. Through the mechanized mixture process (which can be assimilated with scarification of a dump's surface), the permeability and porosity of the rocks were improved, these characteristics being very important for the development of vegetation.

RESULTS AND DISCUSSIONS

Physical, chemical and biological activity analyses

Soil quality and fertility is determined by pedological analyses. Pedological properties are, in fact, defined by all the other properties of the soils: physical, chemical, biological, etc.

Marls, clays, and sands predominate in the sterile material that forms the cover and sterile intercalations. From the point of view of the permeability of the rocks in the open-pit mining perimeters in the Rovinari Mining Basin, we encounter predominantly aquiclude rocks, which retain moisture well and which, in appropriate loosening conditions, do not pose problems for the development of roots.

In Table 2, the results of the physical analyses carried out in the profile laboratories of the Faculty of Mining from the University of Petroșani are centralized on the samples taken from the substrates (soil substitutes, respectively recipes R1-R6) proposed for the experiment.

Table 2. The physical characteristics of the substrates proposed for performing the experiment

Soil recipe	Granulometric composition of the parent material (of the sterile material[1])				Volumetric weight, γ_a [kN/m^3]	Specific weight, γ_s [kN/m^3]	Natural moisture, w [%]	Porosity, n [%]	Pore index, ε
	Clay	Dust	Sand	Gravel					
R1	2.5	7.7	80.59[2]	9.14	20.30	26.44	23.70	37.93	0.61
R2					19.67		23.18	39.60	0.66
R3					19.35		23.63	40.80	0.69
R4					19.35				
R5	33	17	50	-	20.03	26.32	28.1	59.40	0.39
R6	41	52	7	-	17.40	26.22	27.97	48.14	0.93

[1]the sterile material that constitutes the R1, R2, R3, and R4 recipes is the same, and the added manure, compost, and fertilizer do not influence the granulometric composition.
[2]fine sand predominates in proportion higher than 50%.

Table 3 summarizes the results of the chemical analyses carried out in the chemistry laboratory of the Faculty of Mining from the University of Petroșani on the samples prepared before and after the experiment, respectively blank samples and proposed substrates. The values of the chemical indicators were determined by standard methods (ICPA, 2023), measured or calculated, as appropriate.

According to the pH value, the blank samples and the recipes show weak alkaline reactions except for the blank sample PM_5. In all cases, compared to the blank samples, a slight increase in pH was recorded, except for recipe R1 in the case of species S2 (grass+clover) and S3 (grass+alfalfa) where a slight decrease in pH was recorded. Weakly alkaline soils are favorable for alfalfa and clover, which explains their good development (Popescu, 2002).

The EC and the TDS are exactly correlated, being indicators of the salinity level of the soil. A significant decrease in salinity is observed in the case of recipe R6, a decrease attributed to the leaching of soluble salts in the case of a substrate that presented suitable aeration (and implicitly, permeability) conditions due to the content in coal fractions. In general, clays with carbon content and implicitly humic acids have several valuable properties: the formation of structural soil aggregates, contributing to their loosening; loosening of the soil, which allows its aeration and moistening; hygroscopic retention of water due to humic acids; decomposition of humic substances (Scorțariu et al., 2011).

Table 3. Chemical characteristics of soil samples

Sample	pH	EC [µS/cm]	TDS [mg/kg]	W_{higr} [%]	C_{fix} [%]	OM [%]	CO_3^- [%]	Ca^{2+} [mg/kg]	Mg^{2+} [mg/kg]	N [$\cdot 10^3$ [mg/kg]	P [mg/kg]	K [mg/kg]
S1R1	8.20	256	1356.1	1.79	1.11	1.90	5.96	132.3	25.1	1.2	8.6	331
S1R2	8.07	246	1238.5	1.18	1.91	3.35	5.55	164.5	69.8	1.0	27.4	355
S1R3	7.86	226	1151.1	3.64	0.79	1.39	7.60	151.7	74.6	0.7	27.3	328
S1R4	8.04	256	1356.0	1.47	1.34	2.31	6.99	103.2	67.6	0.9	20.6	779
S1R5	7.92	336	1685.6	1.33	0.41	0.68	8.41	129.4	33.3	1.5	37.5	590
S1R6	7.92	896	4492.3	2.60	1.35	2.27	13.66	352.6	120.4	1.2	37.1	506
S2R1	7.25	264	1324.3	1.61	0.62	1.06	7.48	117.8	39.4	1.1	30.4	1221
S2R2	7.93	270	1357.3	1.45	0.60	1.03	7.55	125.9	50.1	1.2	29.4	692
S2R3	7.93	246	1163.8	3.13	0.31	0.53	8.22	107.9	37.4	1.3	16.0	407
S2R4	7.92	288	1447.7	1.41	1.25	2.20	7.33	121.6	36.9	0.9	27.0	622
S2R5	7.93	242	1260.4	1.39	1.33	2.32	7.46	91.8	60.7	1.0	38.2	774
S2R6	7.78	820	4383.1	2.17	3.84	6.44	11.49	340.6	129.1	0.9	28.3	1580
S3R1	7.40	284	1397.6	5.33	0.78	1.34	7.43	98.5	64.3	1.3	14.2	1309
S3R2	7.78	230	1140.7	2.78	1.08	1.81	7.60	108.4	35.2	1.2	14.5	954
S3R3	7.71	266	1317.4	2.67	1.40	2.44	7.02	113.6	35.6	1.2	11.4	1153
S3R4	7.90	258	1359.4	1.30	0.64	1.14	7.11	128.8	40.3	0.7	24.2	1515
S3R5	7.96	276	1464.7	2.13	0.70	1.22	6.66	136.2	23.2	0.8	15.9	912
S3R6	8.02	764	3794.5	2.41	2.34	4.00	12.03	321.6	104.8	0.8	13.4	926
PM_{1-4}	7.49	318	1547.4	0.67	0.03	0.05	6.79	88.4	65.3	2.9	9.6	12
PM_5	7.07	476	2606.0	2.27	0.48	0.85	9.69	184.2	101.3	5.8	5.3	27
PM_6	7.26	1566	7857.2	7.50	10.06	17.09	14.92	793.7	272.3	2.8	13.3	731

PM_{1-4} – blank sample = 100% sterile rocks from the dump (sand, mainly fine, dusty-clay with gravel elements); PM_5 – blank sample = 100% sterile rocks from intercalations (sandy clay); PM_6 – blank sample = 100% sterile rocks from intercalations (coal marl); EC – electrical conductivity; TDS – total dissolved solids; w_{higr} – hygroscopic humidity; C_{fix} – Organic carbon (fixed); OM – Organic mass (Humus); CO_{3-} – Carbonates; Ca^{2+} – Calcium; Mg^{2+} – Magnesium; N – Nitrogen; P – Phosphorus; K - Potassium.

There is also a correlation between OM content and C_{fix}. C_{fix} represents approximately 58% of the mass of OM (DPIRD, 2022). In most of the recipes, OM, and implicitly C_{fix}, increased, except for recipe R6 where a decrease was observed. Following the analyses carried out, it was found that this decrease can be explained by the chemical degradation of OM through oxidation. The highest reduction was registered in the case of peas, as a result of the exposure of the soil to the action of external factors. The degree of coverage of the substrate, in this case, tends to 0.

One of the practices that lead to reduced soil organic matter is over-working and aerating the soil. Since the decomposition of organic matter and the release of carbon are aerobic processes, oxygen stimulates or accelerates the action of soil microbes, which feed on organic matter (Bot & Benites, 2005).

Carbonates (or inorganic carbon) are found in soil mainly as calcium carbonates ($CaCO_3$). Carbonates have a positive role as they prevent soil acidification and limit the transfer of heavy metals from soil to plants (Wang et al., 2015). In large quantities, it causes a significant and unwanted increase in soil reaction, a situation that can reduce the availability of nutrients for plants, and affect the population of microorganisms, their activity, and soil quality. The average carbonate content varies between 1 and 10% (USDA, 2003). In most cases, the carbonate content in the recipes is lower than in the blank samples (or around the initial values), the average content being respected, except for recipe R6 where it was observed to exceed it.

Nutrients are replenished from humus mineralization and fresh organic matter.

Nitrogen is the main nutrient in plant growth. Organic matter and humus, depending on their quality, are the main sources of nitrogen in the soil. Among the species chosen, but also among other plant species, peas are a very good precursor for many crops, because they are harvested early and, most importantly, they have a favorable influence on the structure of the soil, its moisture, and an appreciable amount of OM and N remains in the soil (about 1.5 t D.M. and 70-140 kg N/ha) (Gumovschi, 2021; 2022). Nitrogen content decreased considerably in all recipes compared to blank samples, while phosphorus content increased to a medium level and potassium in most cases recorded a medium to very good level of supply (except for the content of phosphorus in R1 in the case of peas where it decreased insignificantly and of the potassium content in R6 in the case of peas where it decreased slightly, most likely due to leaching). The presence of nodules containing nitrogen-fixing bacteria on the roots of the species was confirmed following the experiment. The remains of these roots contribute to enriching the soil with nitrogen. Although nitrogen-fixing species were used, the reduction of the amount of nitrogen compared to the initial samples is observed, which is explained by the consumption of nitrogen by the plants, volatilization, leaching, but also as a result of harvesting the plants with all their roots (which meant the removal of nitrogen-bearing nodules from the analyzed substrates).

Phosphorus is important for root development. Reduced root development in the first phenological stages indicates a deficiency in phosphorus content. Potassium plays an important role in the storage of nutrients in plants and their fruits and increases the plant's resistance to drought and disease. The two nutrients showed increases in almost all cases, the input generally coming from compost, manure, and fertilizers, or even coal fragments. Some conditions, such as higher humidity, increase their availability.

The calcium content was halved (approximately) in the R5 and R6 recipes compared to the blank samples, while in the other recipes, it increased by 10 to 90% compared to the blank sample.

Magnesium content was halved (approximately) in R6 compared to the blank sample, while R5 had 25 to 50% reductions, and R1-R4 recipes mostly had decreases of up to 40%, and in others increases of up to 15%.

Calcium has an important role as a nutrient, although it is more difficult to assimilate compared to other nutrients, and as a buffer in correcting soil pH, while magnesium has roles in plant metabolism. The decrease in calcium and magnesium is attributed to leaching processes.

The biological activity carried out by soil organisms (bacteria, fungi, worms, earthworms, mice, moles, reptiles, etc.) ensures the processing of organic matter and its transformation into humus and nutrients. Soil organic matter is composed of approximately 85% humus, 10% roots, and 5% organisms. In turn, the organisms are made up of approx. 40% bacteria and actinomycetes (representing microorganisms), 40% fungi and algae, 15% protozoa, mites, worms, and earthworms (representing mesoorganisms), and 5% reptiles and small mammals (representing macroorganisms) (Senicovscaia, 2012; Fengshuo et al., 2023).

The presence of these organisms is indispensable in the soil. Organisms facilitate the decomposition of crop waste and are of particular importance during composting processes (Ruchi & Sunita, 2022).

The presence of these types of organisms was determined by visual observations in the field (in the case of meso and macrofauna) and by microscopic observations in the case of microfauna.

Microorganisms are present both in the sterile material and in the proposed soil recipes. Considering that biological analyses are not the essential object of the project, they were carried out only to confirm the presence of populations without actually counting and tracking their evolution. Bacteria, nematodes, amoebae, algae, fungi, etc. were observed under the microscope (in soil samples and aqueous soil solutions). Since no signs indicating the presence of harmful microorganisms (yellowing, spotting of plants, etc.) were observed on the plants, it can be concluded that these are generally beneficial species.

The presence of mesoorganisms was evident at the end of the experiments (mainly earthworms, but also snails, spiders, ants, forest lice, etc.). Although their presence is attributed to their migration from the adjacent areas, this also happens on a larger scale, i.e. the migration of fauna from the surroundings of the waste dumps, so it is a natural process but more lasting on a larger scale.

In the case of vegetation vessels, the presence of macroorganisms was not reported as a result of the fact that they cannot effectively penetrate the vegetation vessels at the substrate level; the adjacent land is vast and obvious, the vessels are not of interest to macro-organisms, but in the case of some field experiments their access will be facilitated.

Evaluation of the anthropogenic soil quality index corresponding to Rovinari mining basin

The assessment of the soil quality index (SQI) is carried out by (Bhattacharyya et al., 2017; Doran & Parkin, 1994; Lazăr et al., 2017):

- selecting a set of indicators considered to be the most representative of the productive function of the soil;
- the description and classification of the indicators;
- the individual assessment based on the properties of the analyzed soil;
- the overall assessment according to the values of the individual indicators and their importance in soil quality.

The soil quality index is defined by the sum of the products between the individual quality index (QI) and the importance (P) of the quality indicator, according to the equation (Bhattacharyya et al., 2017; Doran & Parkin, 1994; Lazăr, 2010):

$$SQI = \sum_{i=1}^{n}(P_i \times QI_i)$$

where:

P_i - numerical weighting for each soil property indicating its importance in soil quality assessment, %; the cumulative weight for all soil properties will be equal to 1 (100%);

QI_i - the quality index corresponding to each quality indicator (each property) of the soil;

n – the number of quality indicators considered. The number of indicators may vary, as appropriate, which means that this evaluation method can be simplified or developed.

An ideal soil would fulfill all the functions considered important, in which case the SQI would receive the maximum value (5). In reality, the ideal state is impossible to define, but it will be assimilated to a state considered ideal at a given time (based on some properties considered to be the best). The SQI value decreases with worsening soil properties (1 being the lowest value).

Several quality indicators of soils (physical, chemical, and pedological) were considered in the analysis. As a result of the difficult quantification and forecasting of biological behavior, and the fact that the biological analysis was only carried out at an estimative level, the biological indicators were neglected.

Given that soil properties are expressed differently, their standardization was ensured, applying the method of analysis in principal components, ACP (Greenacre et al., 2022), by creating 5 classes for which values from 1 to 5 were given. These values describe the quality of each index, where 1 – very weak quality, and 5 – very good quality (Table 4). This method is used to reduce data complexity, highlight and explain similarities and differences, and correlate results. It is impossible to consider all plant species as the requirements for soil quality can vary widely, but we have referred to general plant requirements.

Eleven indicators were taken into analysis (Table 5). Their importance was expressed as a percentage and all indicators were considered to have the same importance (9%) except for pH which was given 10% importance (to total 100 % pH was chosen as the most important having influences on other soil properties). All the proposed soil recipes (R1-R6) were evaluated, separately according to the species planted to follow the possible positive influences of the chosen species (S1-S3) on the quality of the substrates and the blank samples (PM_{1-4}, PM_5 and PM_6).

The evaluation of the quality index and the performance of comparative analyses led to the some important results.

Improvements were observed in the soil substitutes based on the blank sample PM_{1-4}, in almost all cases, with one exception (S1R1), a situation in which the quality did not worsen but remained constant.

In the case of soil substitutes based on the blank sample PM_5, improvements in their quality were observed in pots with peas and clovers and a deterioration in pots with alfalfa.

The blank sample PM_6, representing the basis of the R6 recipe, although in its initial state (before the experiments) it presented a superior quality to the other two blank samples, after harvesting the plants there was a reduction in the SQI value, i.e. a decrease in the quality of the substrate in the case of peas and alfalfa, while in the case of clover the SQI value remained constant. The S2 species (grass + clover) led to the increase of the SQI value, having a significant contribution in the case of all soil substitutes, with one exception – a situation in which this value remained constant.

In the case of species S1 (peas), out of the 6 recipes, 4 recorded increases in SQI values, one recorded a decrease, and one remained constant. The S3 species (grass + alfalfa) recorded decreases in the SQI values in 2 cases (in one of them the decrease in the quality class from moderate to low was also recorded), in the others there was an increase in it.

Table 4. The values of quality indices depending on soil properties (modified after: Bhattacharyya et al., 2017; Diack & Scott, 2001; Chaudhry et al., 2024; Popescu, 2002; Doran & Parkin, 1994; Lazăr et al., 2017; Alloway, 2008; Munnaf et al., 2020; Epstein & Bloom, 2005; Finck, 1992; Liebenberg et al., 2020; Vigliotti et al., 2020)

QI	1	2	3	4	5
Texture	coarse, fine	coarse, fine	coarse-medium, medium-fine	coarse-medium, medium-fine	medium
Structural stability	unstable structure, the aggregates separate only into small parts	less stable structure, the aggregates separate almost only in small parts	slightly stable structure, the aggregates separate into large and small parts equally	stable structure, the aggregates separate into few small parts	very stable structure, the aggregates do not separate or separate into few large aggregates
Hygroscopic moisture [%]	≤ 1	1.1 – 3	3.1 – 6	6.1 – 9	9.1 – 14
pH	≤ 4.30 / ≥ 10.71	4.31 – 5.00 / 10.01 – 10.70	5.01 – 5.80 / 8.41 – 10.00	5.81 – 6.80 / 7.21 – 8.40	6.81 – 7.20
pH reaction	extremely acidic, very strongly acidic, very strongly alkaline or extremely alkaline	strongly acidic or strongly alkaline	moderately acidic or alkaline	slightly acidic or slightly alkaline	neutral
OM [%]	< 2	2 – 4	4 – 6	6 – 8	> 8
C_{fix} [%]	< 1.16	1.16 – 2.32	2.32 – 3.49	> 3.49	> 3.49
N [10^3 mg/kg]	< 1 / ≥ 24.1	1.1 – 1.4 / ≥ 24.1	1.41 – 2.7 / 12.1 – 24.0	2.71 – 6.1 / 12.1 – 24.0	6.1 – 12.0
P [mg/kg]	≤ 8 / ≥ 144	8.1 – 18 / ≥ 144	18.1 – 36 / 108.1 - 144	36.1 – 72 / 108.1 – 144	72.1 – 108
K [mg/kg]	< 250 / ≥ 2000	250.1 – 500 / ≥ 2000	500.1 – 1000 / ≥ 2000	1000.1 – 1500 / ≥ 2000	1500.1 – 2000
Mg^{2+} [mg/kg]	< 12.5 / ≥ 75.1 for sandy soils, < 17.5 / ≥ 105.1 for dusty soils, < 30 / ≥ 175.1 for clayey soils	12.6 – 25 / ≥ 75.1 for sandy soils, 17.6 – 35 / ≥ 105.1 for dusty soils, 30.1 – 60 / ≥ 175.1 for clayey soils	25.1 – 37.5 / 62.6 – 75 for sandy soils, 35.1 – 42.5 / 87.6 – 105 for dusty soils, 60.1 – 90 / 150.1 – 175 for clayey soils	37.6 – 50 / 62.6 – 75 for sandy soils, 42.6 – 70 / 87.6 – 105 for dusty soils, 90.1 – 120 / 150.1 – 175 for clayey soils	50.1 – 62.5 for sandy soils, 70.1 – 87.5 for dusty soils, 120.1 – 150 for clayey soils
Ca^{2+} [mg/kg]	≤ 400 / ≥ 6000.1	400.1 – 800 / ≥ 6000.1	800.1 – 1000 / 4000.1 – 6000	2000.1 – 6000	1000.1 – 4000
Salinity	very saline	moderately saline	slightly saline	non-saline, very slightly saline	non-saline, very slightly saline
EC [µS/cm]	≥ 1600.1	800.1 – 1600	400.1 – 800	≤ 400	≤ 400
TDS [mg/kg]	≥ 12000.1	9000.1 – 12000	6000.1 – 9000	≤ 6000	≤ 6000

Table 5. Quality indicators, their importance, individual quality index, and aggregate quality index

Species	Soil recipe	Quality indicators Importance of indicator, Pi [%]											SQI
		T 9	SH 9	w_{higr} 9	pH 10	OM/C_{fix} 9	N 9	P 9	K 9	Mg^{2+} 9	Ca^{2+} 9	S/EC/TDS 9	
S1	R1	2	2	2	4	1	2	2	2	3	1	5	2.29
	R2	2	2	2	4	2	2	3	2	4	1	5	2.56
	R3	2	2	3	4	1	1	3	2	4	1	5	2.47
	R4	2	2	2	4	2	1	3	3	4	1	5	2.56
S2	R1	2	2	2	4	1	2	3	4	4	1	5	2.65
	R2	2	2	2	4	1	2	3	3	4	1	5	2.56
	R3	2	2	3	4	1	2	2	2	4	1	5	2.47
	R4	2	2	2	4	2	1	3	3	3	1	5	2.47
S3	R1	2	2	3	4	1	2	2	4	4	1	5	2.65
	R2	2	2	2	4	1	2	2	3	3	1	5	2.38
	R3	2	2	2	4	2	2	2	4	3	1	5	2.56
	R4	2	2	2	4	1	1	3	5	4	1	5	2.65
Blank sample PM_{1-4}		2	2	1	4	1	4	2	1	4	1	4	2.29
S1	R5	4	2	2	4	1	3	4	3	2	1	5	2.74
S2	R5	4	2	2	4	2	2	4	3	4	1	5	2.92
S3	R5	4	2	2	4	1	1	2	3	2	1	2	2.11
Blank sample PM_5		4	2	2	5	1	4	1	1	4	1	3	2.48
S1	R6	2	2	2	4	2	2	4	3	5	1	2	2.56
S2	R6	2	2	2	4	4	1	3	5	5	1	2	2.74
S3	R6	2	2	2	4	3	1	2	3	4	1	3	2.38
Blank sample PM_6		2	2	4	4	5	4	2	3	1	2	2	2.74

T – texture; SH – structural stability; w_{higr} – hygroscopic moisture; OM – organic mass; C_{fix} – organic carbon (fixed); N – Nitrogen; P – Phosphorus; K – Potassium; Mg^{2+} – Magnesium; Ca^{2+} – Calcium; S – salinity; EC – electrical conductivity; TDS – total dissolved solids.

The final (individual) quality indices change compared to the initial ones, some in the sense of improvement, others in the sense of worsening, as a result of the change in the properties of the substrates according to the results of the analyses.
Figure 6 shows the SQI value according to the species - recipe combination.

Figure 6. The SQI value according to the species – recipe combination (see the notations in Figure 3)

Following the application of the proposed calculation method, as an absolute result, clover mixed with grass contributes the most to improving soil quality, followed by peas and only then alfalfa mixed with grass.
Starting from the results obtained from the pedological, physical, and chemical analyses, and considering the existing classifications in the specialized literature [2,17,18,52,55-62] regarding some of the most important soil quality indicators, a new classification of soil quality was proposed (Table 6).

Table 6. Soil quality classes according to SQI value (modified after Supriyadi et al., 2019)

SQI value, soil quality	Quality class	Blank samples	Soil recipes
4.50 – 5, very good	I	-	-
3.50 – 4.49, good	II	-	-
2.50 – 3.49, moderate	III	PM_6	S1R2, S1R4, S1R5, S1R6, S2R1, S2R2, S2R5, S2R6, S3R1, S3R3, S3R4
1.50 – 2.49, weak	IV	PM_{1-4}, PM_5	S1R1, S1R3, S2R3, S2R4, S3R2, S3R5, S3R6
< 1.50, very weak	V	-	-

Thus, it can be seen from the graph above, that a total of 11 recipes are in the moderate quality class while 7 are in a lower class showing weak quality. Among the blank samples, one is of moderate quality (PM_6), and the other two show weak quality.

These classes can be the basis for identifying the right species that accept the existing conditions, but also the opportunities to improve the quality of the soils.
Regarding the quality of the blank samples (so in the initial state or before the experiments), depending on the frequency of their appearance in the table (Table 8), the following hierarchy results:
1. PM_6 (have the best properties; frequency of occurrence: 6);
2/3. PM_{1-4} equal to PM_5 (frequency of occurrence: 3).
So, the best substrate used is PM_6, i.e. coaly marl, and the species that contributed the most to improving the quality of the substrates was the mixture of grass with red clover (S2), followed by peas (S1), then the mixture of grass with alfalfa (S3).

CONCLUSIONS

As a direction to accelerate the restoration of the fertile potential of the degraded mining lands, an increasingly studied variant is the use of sterile rocks in the pedogenesis process. The major objective of the research consists in the identification of a quick modality of solidification of the waste material from the mining dumps in Rovinari mining basin.
The soil recipes were constituted based on sterile materials taken from the same mining perimeter (but a mining perimeter representative for the entire Rovinari mining basin): one average sample from the dump and two samples from sterile intercalations. The average sample was the basis for the creation of soil recipes in different mixtures with manure, compost, and fertilizers. Sterile samples from the intercalations were subjected to analysis and experiment to highlight any better properties they might have compared to the average blank sample.
The physical, pedological, biological, and chemical analyses showed that all samples have characteristics that can be improved so that they can support the development of vegetation.
Some recipes have better qualities than others. Based on the chemical analysis and the quality index, it was determined that among the blank samples, the coaly marl sample (PM_6) has the

best qualities. However, its quality decreased, while the quality of the other 2 blank samples improved, except for the combination S3-R5 (alfalfa - sandy clay).

Starting from the results obtained on the blank samples, selective exploitation of the waste rock according to their characteristics can be recommended. In this regard, the rocks with better characteristics can be deposited at the top of the slopes and safety berms of the final steps of the dumps, and those with weaker characteristics should be deposited in lower areas.

There were increases, decreases, but also stagnation of the QI values, depending on the quality indicators: the low structural stability is caused by the lack of humus, low hygroscopic moisture, etc.; the salt content has decreased due to leaching processes; the content in organic matter and organic carbon was insignificant, with the exception of the coaly marl which presented a very high content in the initial sample, but which decreased during the experiment, the most likely explanation being the fact that these values were influenced by the presence of lignite in relatively large quantities, and less by plant and animal remains, the reduction being caused by degradation processes (oxidation) and possibly by the influence of external factors; nitrogen decreased considerably compared to the content of blank samples, explained by consumption, volatilization, leaching, removal of roots, and, implicitly, removal of nitrogen - bearing nodules; phosphorus and potassium have mostly registered increases, due to the addition of compost, manure, and fertilizers or lignite content; calcium and magnesium have halved, the cause being their leaching, etc.

Following the application of the SQI method, the hierarchy of the species that contribute the most to the improvement of soil quality resulted: I - grass + red clover, II - pea, and III - grass + alfalfa.

Following the research, to revegetate the waste dumps in Rovinari mining basin, it is recommended to use the mixture of universal grass and red clover. The preservation of vegetation on the degraded land and its incorporation into the anthropogenic soil, would enrich it with organic matter, humus, nutrients, etc.

The evaluation of the quality index as proposed aims to ensure the qualitative evaluation of anthropogenic protosols (and not only) and the conditions (more precisely, the plant species) that made it possible to improve them compared to in situ conditions.

The final results of this work can be applied in experimental research carried out in situ. Research will gradually expand to larger areas of degraded land.

ACKNOWLEDGEMENTS

This work was supported by University of Petrosani from research funds (grant number CSU 4283/31.05.2023).

REFERENCES

Al-Arif, M. A., Suwanti, L. T., Estoepangestie, A. S., & Lamid, M. (2017). The Nutrients Contents, Dry Matter Digestibility, Organic Matter Digestibility, Total Digestible Nutrient, and NH_3 Rumen Production of Three Kinds of Cattle Feeding Models. *KnE Life Sciences*, *3*(6), 338-343.

Alloway, B. J. (2008). Micronutrients and Crop Production: An Introduction. In B.J. Alloway (Ed.) *Micronutrient Deficiencies in Global Crop Production* (pp. 1-39). Dordrecht, NL: Springer.

Apostu, I. M., Lazar, M., & Faur, F. (2023). A review of possibilities for accelerating the pedogenesis on mining waste dumps. In Proceedings of the 3rd EURECA-PRO Conference on Responsible Consumption and Production (Extended abstract). Chania, Crete, GR, 26-29 September 2023.

Bhattacharyya, P., Padhy, S. R., Shahid, Md., Dash, P. K., Nayak, A. K., & Gangaiah, B. (2017). Soil Quality Index under Organic Farming. In B.G. Angaiah, A.K. Undu, K.A. Birami, S. Swain, T. Subramani, S.K.Z.A. Ahmed (Eds.) *Organic Farming in Tropical Islands of India* (pp. 260–267). Port Blair, India: Shri Vignesh Prints.

Bosch-Serra, A. D., Cruz, J., & Poch, R. M. (2023). Soil Quality in Rehabilitated Coal Mining Areas. *Applied Sciences*, *13*, 9592.

Bot, A., & Benites, J. (2005). *The importance of soil organic matter. Key to drought-resistant soil and sustained food production.* Rome, IT: Food and Agriculture Organization of the United Nations (FAO).

Brejda, J. J., Moorman, T. B., Karlen, D. L., & Dao, T. H. (2000). Identification of regional soil quality factors and indicators I. Central and southern high plains. *Soil Science Society of America Journal*, *64*(6), 2115-2124.

Brujan, M., & Rotunjanu, I. (2015). Assessment of the impact of mining activities from the open pits of the Jilt basin on land surfaces and rehabilitation solutions (in Romanian). In Proceedings of the 6th Balkan

Mining Congress. Petroșani, RO, 20-25 September 2015.
Buscot, F. (2023). Fungi including mycorrhizal fungi. In M.J. Goss, M. Oliver (Eds.) *Encyclopedia of Soils in the Environment, 2nd ed.* (pp. 49-60). Amsterdam, NL: Elsevier.
Chaudhry, H., Vasava, H. B., Chen, S., Saurette, D., Beri, A., Gillespie, A., & Biswas, A. (2024). Evaluating the Soil Quality Index Using Three Methods to Assess Soil Fertility. *Sensors*, *24*, 864.
Cherubin, M. R., Karlen, D. L., Franco, A. L. C., Cerri, C. E. P., Tormena, C. A., & Cerri, C. C. (2016). A Soil Management Assessment Framework (SMAF) Evaluation of Brazilian Sugarcane Expansion on Soil Quality. *Soil Science Society of America Journal*, *80* (1), 215-226.
Cojocaru, O., Abramov, A. (2023). Dynamics of ecological and agro-ecological indices (under conditions of physical and chemical degradation) of soils researched on the genetic horizons. *AgroLife Scientific Journal, 12* (1), 40–52.
Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2022). *Introduction to algorithms*, *4th ed.* Massachusetts, USA: The PIT Press.
da Silva, G. O. A., Southam, G., & Gagen, E. J. (2023). Accelerating soil aggregate formation: a review on microbial processes as the critical step in a post-mining rehabilitation context. *Soil Research*, *61*, 209-223.
Diack, M., & Scott, D. E. (2001). Development of a soil quality index for the Chalmers silty clay loam from the Midwest USA. In D.E. Scott, R.H. Mohtar, G.C. Steinhardt (Eds.) *Sustaining the global farm* (pp. 550-555). West Lafayette, IN, USA: ISCO.
Doran, J. W., & Parkin, T. B. (1994). Defining and Assessing Soil Quality. In J.W. Doran, D.C. Coleman, D.F. Bezdicek, B.A. Stewart (Eds.) *Defining Soil Quality for a Sustainable Environment, 35* (pp. 3-21). Madison, WI: SSSAJ.
Dumitru, M., Cărăbiș, D., Pârvan, L., & Sârbu. C. (2016). Environmental rehabilitation of mining dumps. *Agriculture and Agricultural Science Procedia*, *10*, 3-9.
Eldor, P., & Clark, F. E. (2013). *Soil microbiology, ecology and biochemistry*. San Diego, CA, USA: Academic Press, Inc.
Epstein, E., & Bloom, A. J. (2005). *Mineral Nutrition of Plants: Principles and Perspectives, 2nd ed.* Sunderland, MA: Sinauer Associates, Inc. Publishers.
Faur, F., Lazăr, M., & Apostu (Nyari), I.-M. (2019). Substantiating the decision regarding the ecological reconstruction of mining waste dumps – Case study for Lupeni Dump. *Quality - Access to Success*, *20*, 1, 235-240.
Fengshuo, L., Hossein, G., Guangliang, C., Jiayin, L., Shuang, M., Chang, L., Wenwei, S., Xiuling, C., Mozhen, C., Peiwen, W., Yao, Z., & Aoxue, W. (2023). Microbiome - based agents can optimize composting of agricultural wastes by modifying microbial communities. *Bioresource Technology*, *374*, 128765.
Finck, A. (1992). *Fertilizers and Fertilization - Fundamental Principles and Instructions for Fertilization of Crops (in German), 2nd ed. (revised).* Berlin, DE: Wiley VCH: Weinheim.
Fodor, D., & Lazăr, M. (2006). Occupation and ecological rehabilitation of land in the Oltenia area (In Romanian). *AGIR Bulletin*, *3,* 37-31.
Fodor, D., & Smeu, A. C. (2013). Reintroducing the internal waste dump Tismana in the agricultual circuit. *Annals of the University of Petrosani - Mining Enginneering, 14,* 171-186.
Gerke, J. (2022). The Central Role of Soil Organic Matter in Soil Fertility and Carbon Storage. *Soil Systems*, *6*, 33.
Greenacre, M., Groenen, P. J. F., Hastie, T., D'Enza, A. I., Markos, A., & Tuzhilina, E. (2022). Principal component analysis. *Nature Reviews Methods Primers, 2*, 100.
Gumovschi, A. (2021). *The Field Crops Farmer's Handbook, Part I (in Romanian)*. Chişinău, MD: UCIP IFAD.
Gumovschi, A. (2022). *The Field Crops Farmer's Handbook, Part II (in Romanian)*. Chişinău, MD: UCIP IFAD.
Jury, W., Horton, R. (2004). *Soil physics*. John Wiley&Sons, Inc.: Hoboken, New Jersey.
Khalidy, R., Arnaud, E., & Santos, R. M. (2022). Natural and Human-Induced Factors on the Accumulation and Migration of Pedogenic Carbonate in Soil: A Review. *Land*, *11*, 1448.
Lazăr, M. (2010). *Rehabilitation of degraded lands (in Romanian).* Petroșani, RO: Universitas PH.
Lazar, M., Dunca, E. C., Faur, F., Apostu, I.-M., & Irimie, S. (2023). Study on the Soil Formation Process on the Mining Waste Dumps from Jiu Valley (Romania). A Case Study. In J.A. Benítez-Andrades, P. García-Llamas, Á. Taboada, L. Estévez-Mauriz, R. Baelo (Eds.) *Global Challenges for a Sustainable Society (*pp. 247–258). Cham, DE: Springer.
Lazăr, M., Faur, F., Dunca, E., & Ciolea D. I. (2017). New methodology for establishing the optimal reuse alternative of degraded lands. *Environmental Engineering and Management Journal*, *16(*6), 1301–1308.
Liebenberg, A., van der Nest, J. R., Hardie, A. G., Labuschagne, J., & Swanepoel, P. A. (2020). Extent of Soil Acidity in No-Tillage Systems in the Western Cape Province of South Africa. *Land*, *9*, 361.
Miller, A. J. (2014). Plant mineral nutrition. In *eLS.* Chichester, UK: John Wiley & Sons, Ltd.
Munnaf, M. A., Haesaert, G., Van Meirvenne, M., & Mouazen, A. M. (2020). Site-specific seeding using multi-sensor and data fusion techniques: A review. In D.L. Sparks (Ed.) *Advances in Agronomy, 161* (pp. 241-323). Amsterdam, NL: Elsevier.
Peñaranda, B. M. A., Alarcón, M. V., Gómez, L. I., & Navarro, P. J. (2020). Methods of soil recovery in quarries of arid and semiarid areas using different waste types. *Spanish Journal of Soil Science*, *10*, 2, 101-122.
Popescu, C. (2002). *Pedology. General part.* Craiova, RO: Universitaria PH.
Predoiu, M., Faur, F., Lazăr, M., Apostu, I.-M. (2023). Analysis of the Stability State of Jilț North Internal

Dump in the Perspective of its Ecological Reconstruction. *Mining Revue*, *29*, 3, 1-13.

Ruchi, S., & Sunita, D. (2022). Composting process: Fundamental and molecular aspects. In S. Jastin, K. Ajay, S. Joginder (Eds.) *Relationship Between Microbes and the Environment for Sustainable Ecosystem Services, 1* (pp. 239-265). Amsterdam, NL: Elsevier.

Schulte, R. P. O., Creamer, R. E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C., & O'hUallachain, D. (2014). Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. *Environmental Science & Policy*, *38*, 45-58.

Scorţariu, O., Guran, I., & Lazăr, M. (2011). Obtaining anthropogenic soils from waste rock for reclamation of damaged land by coal pits from Oltenia. In Proceedings of the 22nd World Mining Congress, Istanbul, TR, 11-16 September 2011.

Senicovscaia, I. (2012). Biota of degraded soils and methods for its restoration. *AgroLife Scientific Journal, 1*(1), 78–83.

Singer, M. J. (2015). *Basic Principles of Pedology. Reference Module in Earth Systems and Environmental Sciences.* Amsterdam, NL: Elsevier.

Sung, C. T. B., Ishak, C. F., Abdullah, R., Othman, R., Panhwar, Q. A., & Aziz, M. A. (2017). Soil Properties (Physical, Chemical, Biological, Mechanical). In M.A. Ashraf, R. Othman, F. Ishak (Eds.) *Soils of Malaysia, 1st ed.* Boca Raton, FL, USA: CRC Press.

Supriyadi, S., Widyatmani, D., Desmiasari, N., Rahmah, A.A., Haryuni, H., & Sumani, S. (2019). The Assessment of Soil Quality Index for Paddy Fields with Indicator Biology in Jatipurno Districts, Wonogirl. *Modern Applied Sciences, 14* (1), 20.

Vigliotti, M., Busico, G., & Ruberti, D. (2020). Assessment of the Vulnerability to Agricultural Nitrate in Two Highly Diversified Environmental Settings. *Environments*, *7*, 80.

Wang, C., Li, W., Yang, Z., Chen, Y., Shao, W., & Ji, J. (2015). An invisible soil acidification: Critical role of soil carbonate and its impact on heavy metal bioavailability. *Scientific Reports*, *5*, 12735.

Weil, R. R., & Brady, N. C. (2016). *The nature and properties of soils. 15th ed.* London, UK: Pearson.

***Department of Primary Industries and Regional Development (DPIRD) (2022). What is soil organic carbon? Agriculture and Food, Government of Western Australia.

***Institute of Energy Studies and Designs (ISPE) (2012). Environmental Strategies Collective. Environmental impact report - Rovinari (in Romanian). Report no. 8343/2015-1-S0084533-N0, Bucharest, RO.

***IUSS Working Group WRB (2022). *World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps, 4th ed.* Vienna, AU: International Union of Soil Sciences (IUSS).

***Ministry of the Environment and Water Management (MMGA) (2005). Code of Good Agricultural Practices for Water Protection Against Nitrate Pollution from Agricultural Sources (in Romanian), Bucharest, RO.

***National Meteorological Administration (ANM) (2023). Multiannual climatological characterization 1961-2022, Bucharest, RO.

***National Research-Development Institute for Pedology, Agrochemistry and Environmental Protection (ICPA) (2023). Evaluation of soil nutrient content (in Romanian), Bucharest, RO.

***United States Department of Agriculture (USDA) (2003). Garsis Series, National Cooperative Soil Survey, Tentative Series, Rev. AJC/JS, 3, 2003.