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PROPOSAL FOR A QUICK METHOD FOR CHOOSING PLANT SPECIES TO ACCELERATE PEDOGENESIS ON WASTE DUMPS

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Abstract: *Mining is one of the activities that require large areas of land for the storage of sterile rocks resulting from the extraction of useful mineral substances. Waste dumps are wide-spread, are unpleasant components of the landscape causing a negative visual impact, the modification of ecosystems and their functions, environmental pollution (depending on their content, it can result atmospheric pollution by entrainment of dust particles and powders by winds, generation of acid waters, land and soil pollution with trace elements, etc.), and may present risks for the objectives in the area as a result of the sliding potential. The waste dumps consisting of inert rocks like sands, clays, and dust in different mixtures, which present various degrees of aeration and permeability and which lack the fertility given by organic matter, need proper interventions and works to support the development of more valuable plants and to reintegrate them into the natural landscape. The research presented in this paper aims to identify the necessary steps in order to accelerate the pedogenesis process on mining dumps and, as a result, a logical scheme type method was developed that could be easily applied to any type of mining dump. Also, the logical scheme was applied and verified through an experimental study carried out at the level of the interior dump of North Pesteana open-pit from Rovinari mining basin, Romania.*
Keywords: *Anthropogenic soils, dumps, fertility, plants, protosols*

1. Introduction

The soil is formed under special conditions at the interaction between the atmosphere, lithosphere, hydrosphere and biosphere, but the actions/events carried out within the anthroposphere, which cannot be prevented or removed, cause major changes at the soil level, both qualitatively and quantitatively, which is a real environmental problem.

On mining affected lands, the remaining lithological materials (sands, clays, dusts, marls) lack fertility, that property that defines an evolved soil capable of supporting the development of vegetation. These materials constitute anthropogenic protosols, undeveloped soils in terms of the physical, chemical, biological and pedological properties that define them [1].

On anthropogenic soils (anthropogenic protosols) in the early phase of their formation as fertile soil, in order to support the growth and development of vegetation, it is necessary to apply some amendments (chemical fertilizers, compost, sludge from water treatment plants, manure, wood waste, etc.) [2, 3, 4].

In the case of waste dumps that do not contain harmful or toxic elements and that present appropriate characteristics and structure or whose conditions can be improved, the constituent rocks represent the necessary inorganic base. Although in low and variable proportion, depending on the type of rocks, reaching or even exceeding 10%, organic matter plays an essential role in the functions of a healthy soil and has positive effects on the physical, chemical and biological characteristics of the soil [5, 6, 7, 8, 9, 10].

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Similar to lands affected by mining activities or natural phenomena, partially or totally destroyed soils can be restored, rehabilitated (recovered) or regenerated. Restoration refers to returning soil at least to its original conditions (or even improving the soil to a superior class of fertility), while rehabilitation is the process that initiates or accelerates recovery from its historical trajectory, and regeneration refers to the total replacement of original conditions. Restoration and regeneration represent long-term, expensive activities that face major challenges, such as: extensive areas with a wide variety of land and soil uses, achieving a fair balance between biodiversity conservation and improving the well-being of the population, etc. Rehabilitation focuses on historical or pre-existing conditions, only as models or references [11, 12].

Regardless of the option, it is desired to ensure the health, integrity and sustainability of resources and ecosystems, and concerns in solving these types of problems are numerous. Depending the country and some specific conditions (regarding the types of rocks in sterile dumps, local climatic conditions, and other ecological futures) the literature presents diverse case studies with more or less original solutions [13, 14, 15, 16, 17, 18].

Generally, the optimal solution is to support the recovery of the soil. This type of intervention allows the use of local resources it is an economic advantage with positive effects for the neighbouring communities.

In Romania, the use, improvement, conservation, and protection of the soil is the responsibility of persons who own the lands and constructions of any nature, including mining perimeters. Law 246/2020 regarding the use, conservation, and protection of soil [19] must be respected and applied. The experimental study, presented in the paper, was carried out in accordance with the limitations imposed by the legislation in force and the specialized studies elaborated by the Research Institute for Pedology and Agrochemistry (ICPA) or by the Offices of Pedological and Agrochemical Studies (OSPA) [20, 21].

2. Important stages in pedogenesis process

The main characteristics of the dumped rocks, which affect productivity, are the following: excessive texture (too sandy or too clayey), excessive parent material content, low humus content, low nitrogen, potassium, phosphorus, micronutrients, air-water regime deficient, reduced biological activity. Revegetation projects play a significant role in improving soil quality and mitigating the negative effects of mining activities on land and soil as they could accelerate natural soil recovery processes on waste dumps and increase the biological diversity of these degraded lands [22, 23, 24, 25].

The main aspects in pedogenesis process were followed in order to develop a logical scheme for accelerating pedogenesis on sterile dumps. This is a method that seeks to synthesize the steps to be taken, highlight and consider potential influencing factors in order to achieve the desired results.

The advantages of logical schemes are that they are simple, clear, easy to understand, summarize the stages of solving a problem, and ensure quick visualization of actions. A logical scheme represents the totality of operations needed to solve a problem in an orderly way. An algorithm can be used in any field, but it is mostly used in mathematics and computer science.

The theoretical stages of developing a logical scheme consist of studying, formulating, and analyzing the problem, structuring it in standardized forms, and programming (coding in a programming language). After the development follows the verification and elimination of possible errors, the improvement of the program, the creation of the instructions for use, and the actual use of the program in practice [17, 26].

Several stages were taken into account in the development of the logical scheme [5, 6, 7, 8, 9, 10, 27, 28, 29, 30]:

I – ensuring a base of uncontaminated inorganic matter;
II – providing organic matter and the necessary nutrients;
III – creating the right conditions for aeration (porosity);
IV – creating the right moisture conditions;
V – choice of species;
VI – identifying and writing the optimal recipe and species.

Within the proposed scheme, sequential, alternative, and repetitive structures are found and decision and procedural blocks predominate. Alternative and repetitive structures are based on a condition imposed by the decision block. The procedures are applied according to the decision (starting from the imposed condition), and the conditions are represented by several key questions whose answers must be satisfactory to fulfill the process of accelerating pedogenesis on sterile dumps.

3. The proposed method for accelerating pedogenesis on anthropogenic soils

To simplify the presentation of the scheme, the decision blocks were numbered from 1 to 8, each block being assigned a key question:

1. Does it contain toxic, dangerous substances?
2. Does it contain at least 5% organic matter?
3. What is the nutrient content (macro and micronutrients)? The step is applied first for macronutrients until the content is established as being optimal, then repeated for micronutrients.
4. Optimal micronutrient content? If not, the cycle of checking nutrient content/level is repeated until the micronutrient content is also optimal.
5. Does the material have a suitable porosity for most crops (30 – 60 %)?
6. Does the material have a suitable moisture for most crops (35 – 75 %)?
7. Does the chosen species yield (> 75%)?
8. Is the dry matter content satisfactory (> 25%)?

The elaborated logical scheme is presented in stages in Figures 1 – 6.

The first step is represented by the choice of the objective, namely the sterile dump on which the intervention is desired to accelerate the pedogenesis process. The logical scheme can be applied to any sterile dump for which the physical stability conditions have been ensured.

Figure 1 shows the scheme for ensuring the base of uncontaminated inorganic matter. The presence and content of toxic, dangerous substances must be checked. If the material does not contain such substances, so it is uncontaminated, you can proceed to the next step. Otherwise, it is necessary to develop the decontamination procedure that can be carried out by [28, 29]:

- phytoremediation – a method that involves the use of plants to extract and eliminate pollutants from the soil or sterile dumps by absorbing them through the roots;
- chemical methods – involve the use of chemical treatments to carry out reduction and oxidation reactions.

After decontaminating the sterile material, we can proceed to the next step.

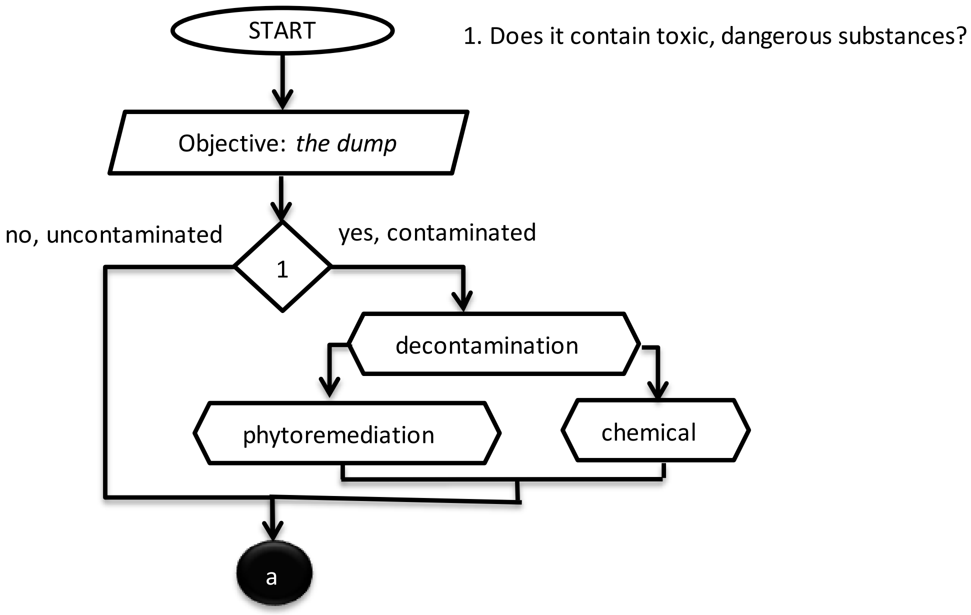

Fig. 1. Scheme for ensuring the base of uncontaminated inorganic matter

Figure 2 shows the scheme for providing organic matter and the necessary nutrients. Identifying and verifying the content in organic matter, macronutrients, and micronutrients is required. Organic matter has multiple and important roles, its absence negatively influencing the physical, chemical, and biological characteristics of the soil. Nutrients support the healthy growth of plants, and their lack is not desired as it raises development problems.

One of the important roles that organic matter has is that of supporting the nutrient cycle and mobilizing nutrients for their efficient use by plants.

Depending on the type of soil, organic matter is found in variable amounts. In the experiments carried out, it was chosen to impose a content of at least 5 % organic matter, the logic scheme being designed according to this value, but it can be modified, as necessary.

If the sterile material contains at least 5 % organic matter, we can proceed to the next step. Otherwise, the organic matter enrichment procedure is applied until the imposed condition is met using one or more of the following methods: crop rotation, use of perennial crops, year-round ground cover, incorporation of unharvested plant residues into the soil (organic waste), the use of compost, organic fertilizers, and, if necessary, bio coal to supplement soil carbon, animal husbandry and grazing (but avoiding overgrazing) are methods that balance the level of soil organic matter or even artificial organic fertilizers (not wanted, but sometimes necessary) [5, 6, 7, 8, 27, 30].

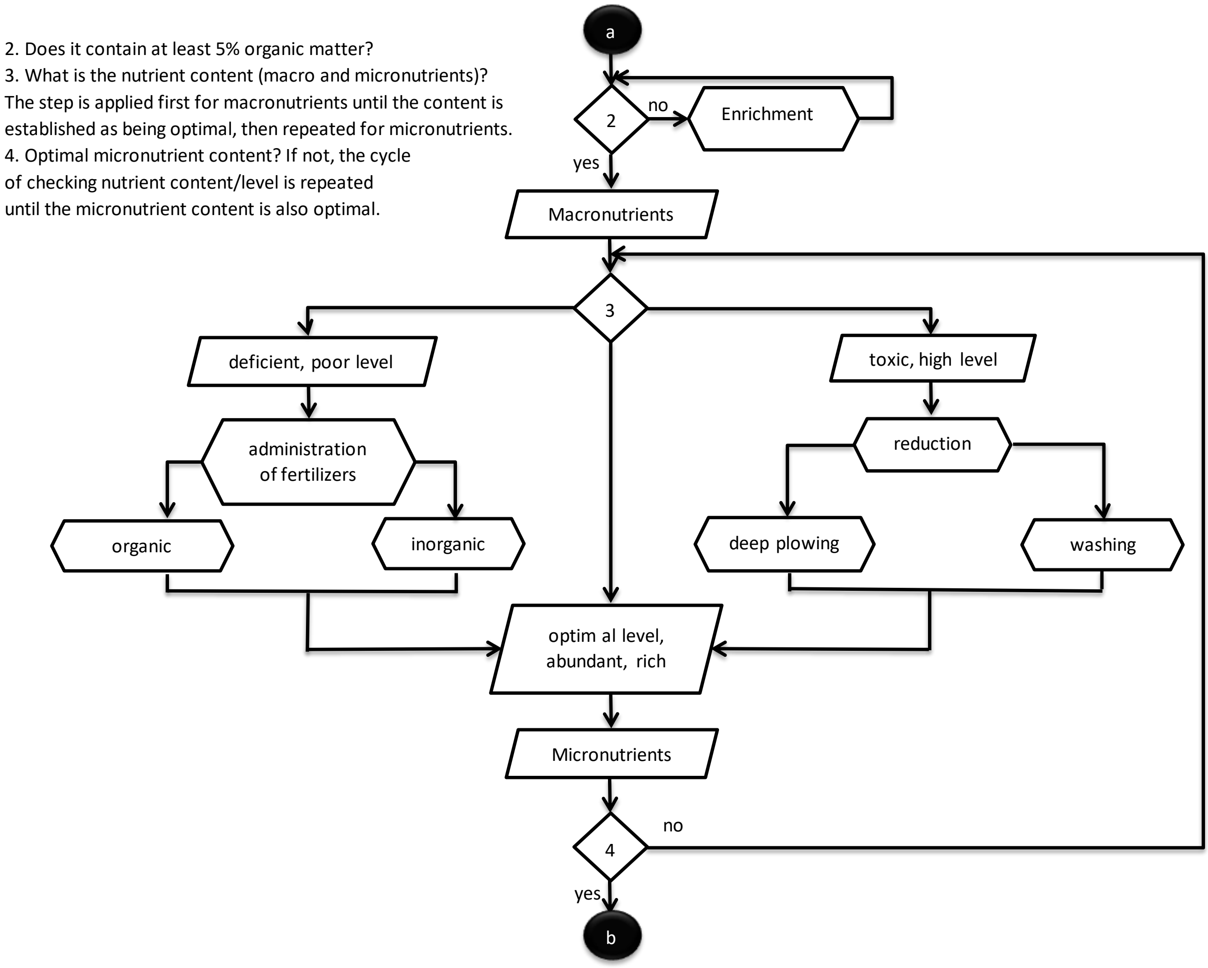

Fig. 2. Scheme for providing the necessary organic matter and nutrients

The next condition imposed is that the material contains nutrients in optimal amounts. If the nutrient level is optimal we can proceed to the next step. Otherwise, if the level of nutrients is deficient, the administration of organic or inorganic fertilizers is required. If the level of nutrients is high and toxic, it is required to reduce them through procedures such as deep plowing or washing. The step is applied first for macronutrients until the content is optimal, then it is repeated for the micronutrients until their content is also optimal.

Figure 3 shows the scheme for creating the right aeration (porosity) conditions. Although some plants also grow in soils with higher or lower loosening degrees, most crops prefer medium loosening conditions. A porosity between 30 – 60 % ensures the proper fixation and development of the roots in the soil and influences the permeability ensuring good water drainage.

As long as this condition is satisfied (porosity between 30 and 60 %), it is possible to proceed to the next stage. Otherwise, if the porosity is less than 30 %, intervention on the material is required through loosening procedures, and if the porosity is greater than 60 %, intervention on the material is required through compaction procedures, until the imposed condition is satisfied.

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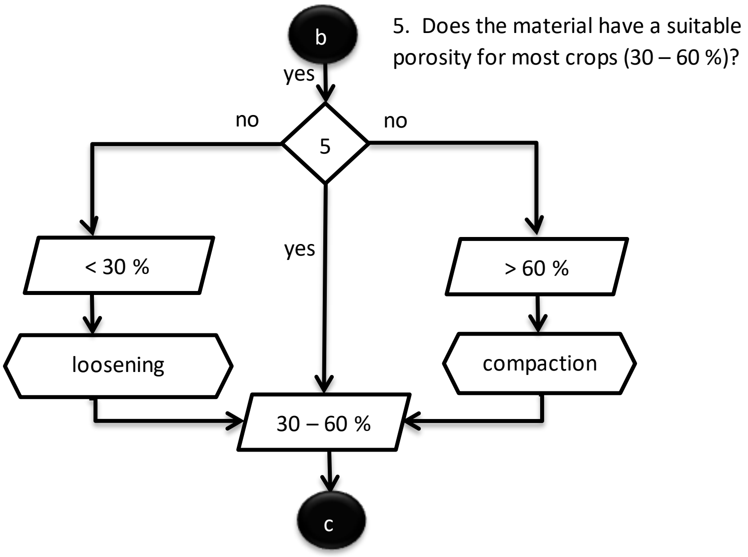

Fig. 3. Scheme for creating suitable aeration conditions (porosity)

Figure 4 shows the scheme for creating the optimal moisture conditions. In low moisture to dry conditions (< 35 %) or high moisture to saturated conditions (> 75 %), experienced for long term (days, weeks, or even longer), plants can be affected to death by drying or rotting. Depending on the type of plant and especially the stage of development, the effects of substrate moisture may appear sooner or later.

As long as the moisture condition is satisfied (35 – 75 %), we can proceed to the next stage. Otherwise, if the moisture is lower than 35 %, intervention through irrigation procedures is required, and if the moisture is higher than 75 %, intervention through drainage procedures is required, until the imposed condition is satisfied.

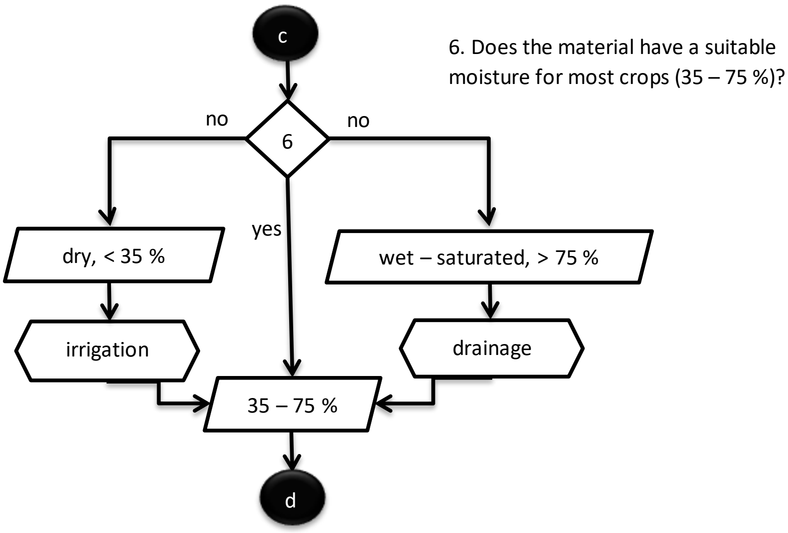

Fig. 4. Scheme for creating the right moisture conditions

Figure 5 shows the scheme for choosing species. The species are chosen so that they ensure a satisfactory yield (> 75 %) and a dry matter (D.M.) quantity of at least 25 %. Since it is not known how species will develop on a substrate constituted based on the previous stages, tolerant species are chosen one by one. Also, the species must have beneficial effects on the quality of the substrate, and experiments are carried out on a small scale (in pots) on the basis of which the yield and dry matter content are evaluated.

If the yield is not satisfactory (< 75 %), a new species is selected. If the yield is satisfactory (> 75 %), the dry matter content is checked. If the D.M. is < 25 %, a new species is selected. When the condition D.M. > 25 % is satisfied, we can proceed to the next stage.

This stage is long lasting. To increase the chances of obtaining the desired results, it is recommended to carry out experiments in pots using several plant species in parallel.

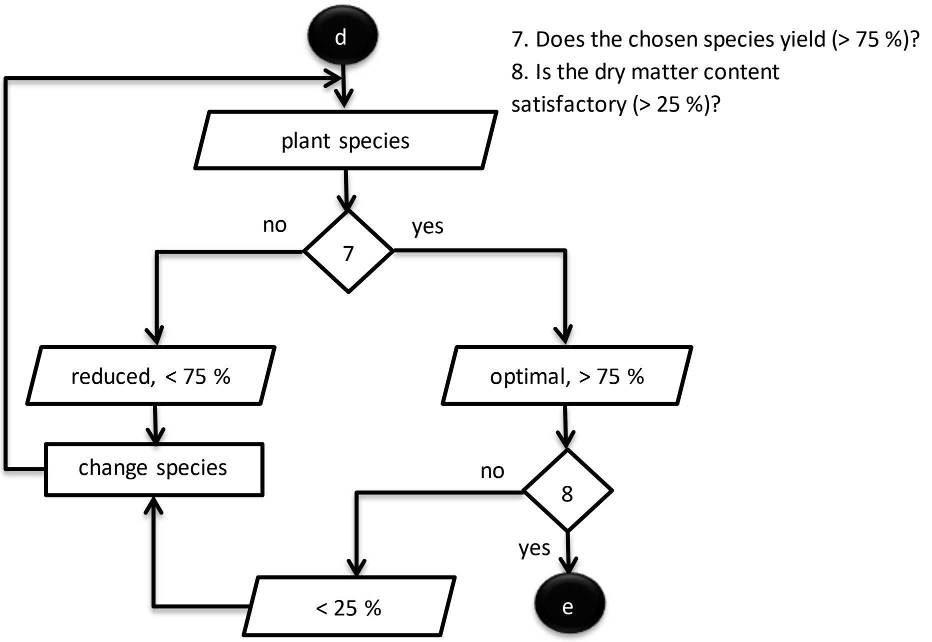

Fig. 5. Scheme for choosing species

Figure 6 shows the scheme for identifying and writing the optimal soil mixture. This stage is reached only when all the required conditions have been met. At this moment, the soil mixture and the plant species that best accept the given conditions are written.

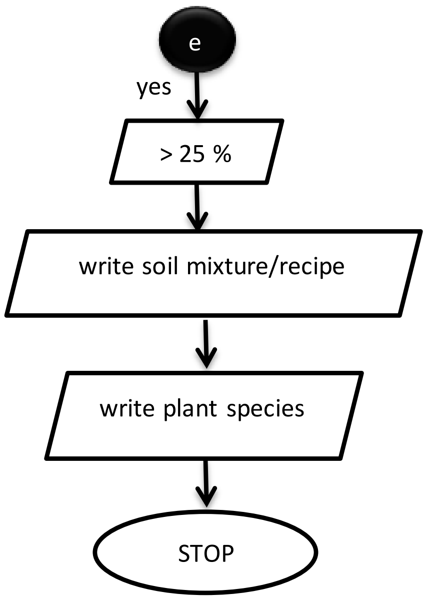

Fig. 6. Scheme for identifying and writing the optimal soil mixture and plant species

These species will be incorporated into the sterile material, even through deeper plowing (20 – 50 cm), aiming from now on the enrichment the sterile material with organic matter and nutrients (without further adding organic and mineral fertilizers). From now on, the pedogenesis process can continue naturally, without human intervention, these interventions being necessary only in the planting, monitoring, and maintenance stage depending on the future uses of the land.

4. Results and discussions

The proposed method for accelerating pedogenesis on anthropogenic soils was applied and verified through an experiment. The case study was carried out at the level of the internal dump of the North Pesteana lignite open-pit, in the Rovinari mining basin, Romania (Figure 7).

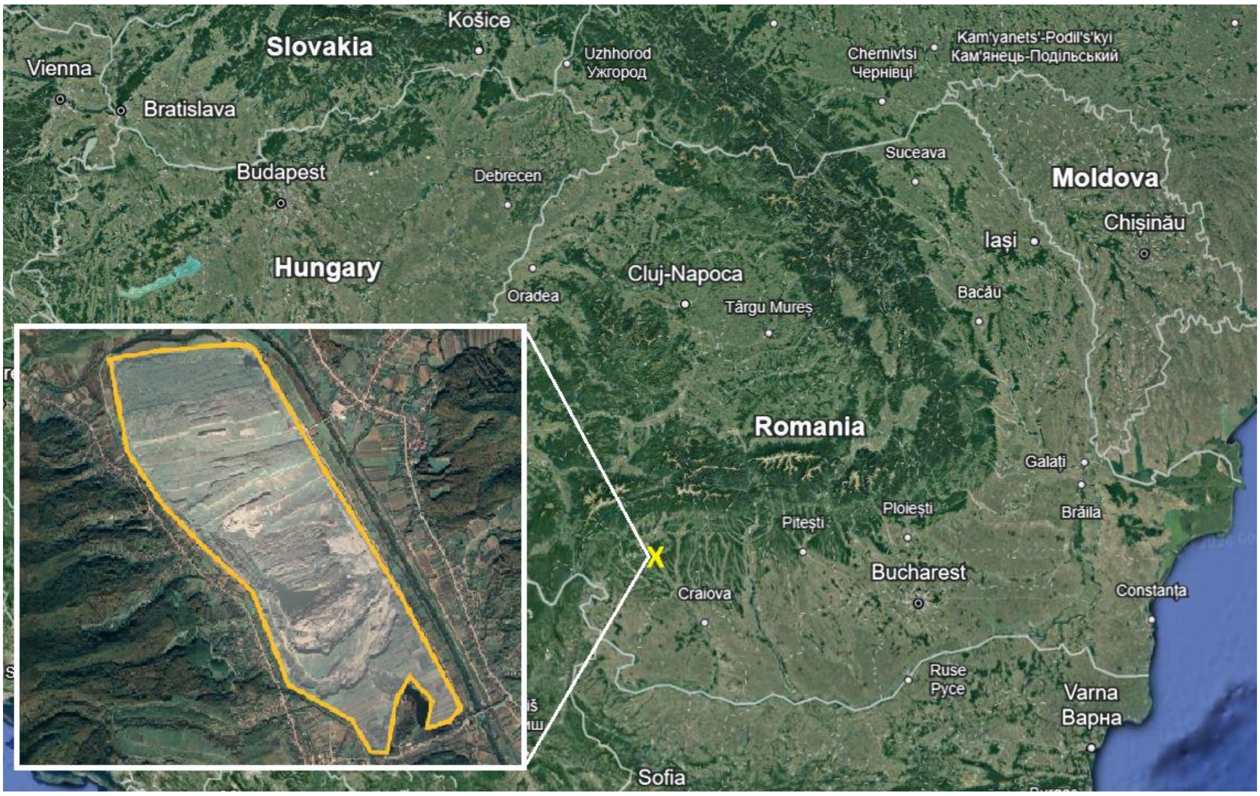

Fig. 7. Location of North Pesteana mining perimeter – Rovinari Mining Basin, Romania

The 8 stages considered to be essential were taken into account when carrying out pot experiments (Figure 8). Following the physical, chemical, and pedological analyzes carried out on the sterile material from the dump, the following were found [31]:

- the sterile material does not contain toxic or dangerous substances, it is made up only of clays, sands, and marls and different mixtures of these types of rocks, representing the inorganic basis necessary in the pedogenesis process;
- the sterile material is poor in organic matter and nutrients, but in order to increase the content of micro and macro elements to a level considered optimal, the experiment assumed:
  - on one side, the enrichment of sterile material with nutrients using fertilizers (a fertilizer with a content of macroelements N - P - K (13% - 5% - 24%) and a series of microelements (Fe, S, MgO , Mn, Zn, Cu, B) with slow release, for tracking the way in which the growth of some plants is supported,
  - and on the other side, the possibility of finding a soil substitute (for which mixtures of waste, compost, and cow manure in different proportions were created) that would support the growth of some plants with an ameliorating role, with the aim of the subsequent incorporation of them in the sterile material (for enrichment with organic matter).
- the sterile material has a relatively high degree of compaction as a result of the use of high-tonnage dumping trucks, which influenced the permeability and porosity of the rocks in the sense that they are moderately to hardly permeable, with adequate to insufficient ventilation. In order to improve these conditions, mechanized and manual loosening works were carried out;
- the sterile material, at the time of sampling, showed a wet to dry state, respectively a humidity between 3.65 – 27.97 %. These variations are determined both by the testing depth (20 cm) and by short-term weather conditions. In order to improve the humidity conditions, watering norms were established depending on the daily amount of precipitation;
- the productivity was estimated by the soil coverage index method, based on which a normal coverage was found, the surfaces of all pots being occupied in a proportion of at least 100% two months after sowing and was evaluated according to the plant mass obtained and compared with the theoretical mass known from the long-term experiences of the farmers and guaranteed by the seed producers, according to which it was found that the production was adequate;
- the dry matter (D.M.) represented between 24 and 50 % of the mass of the plant in its natural-moist state, the difference representing the water content of the plant.

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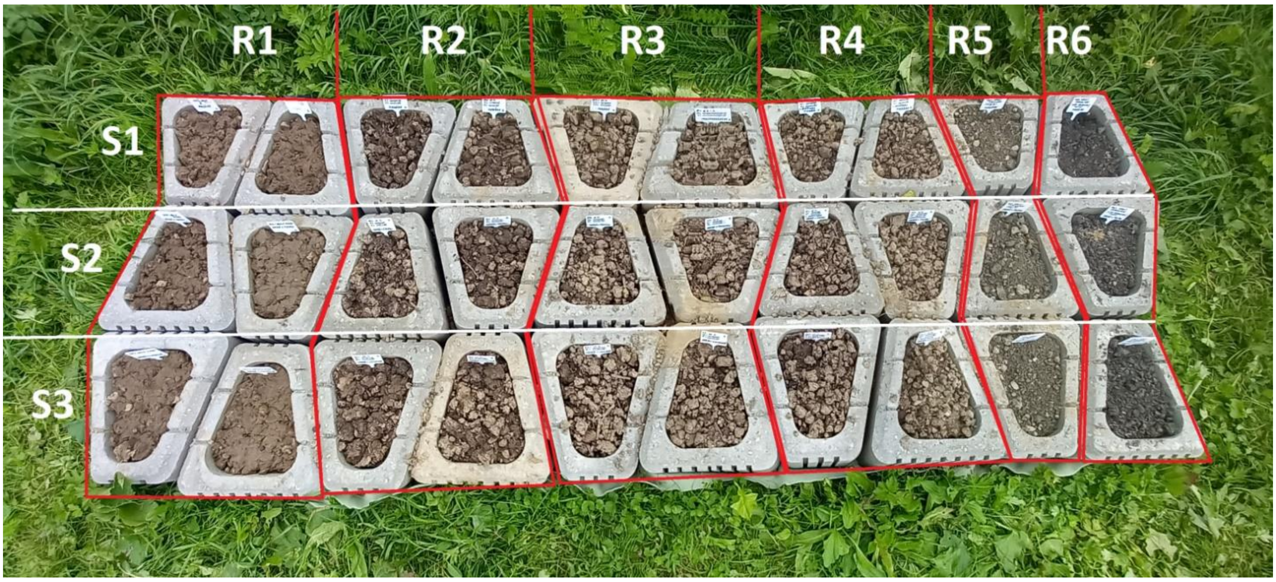

Day 1

R3 – day 34

S1R4 – day 62

S2R1 – day 77

R1 = 100 % sterile material (blank sample); R2 = 90 % sterile material + 5 % compost + 5 % manure; R3 = 85 % sterile material + 10 % compost + 5 % manure; R4 = 85 % sterile material + 10 % compost + 5 % manure + fertilizer; R5 = 100 % sterile material from intercalations (sandy clay; blank sample); R6 = 100 % sterile material from intercalations (coaly marl; blank sample); S1 = green peas; S2 = 50 % red clover + 50 % grass; S3 = 50 % alfalfa + 50 % grass.

Fig. 8. Photo captures during the experiment

Table 1 shows data on the mass of the plant in its natural-wet state, respectively the mass of the dry matter.

Table 1. Plant mass

Soil receipt / **Plant species**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**
Green plant mass, kg/m^2						
Peas (with grains)	1.6	1.1	2.0	1.1	3.2	0.2
Grass + red clover	6.6	4.5	2.7	4.5	7.7	8.1
Grass + alfalfa	5.2	4.0	3.5	6.6	8.2	9.4
Dry plant mass, kg/m^2						
Peas (without grains)	0.4	0.4	0.56	0.42	0.72	0.12
Grass + red clover	1.55	1.15	0.65	1.43	2.04	2.62
Grass + alfalfa	1.21	1.01	0.8	1.89	2.53	3.22

Going through all the stages imposed by the logical scheme, following the experiment we concluded:

- quantitatively, good results were obtained in most of the pots, and the pots with alfalfa generally offered (R3-R6) larger amounts (up to 48%) of plant mass than those with clover.

- the dry matter of the plant varied between 33 and 50 % for peas and between 24 and 35 % for herbaceous species. The difference represents the amount of water contained in the mass of the plant, being greater in mixtures of herbaceous plants.
- the optimal soil mixture ware identified as follows:
  - peas provide the largest amounts of D.M. in the case of substrates consisting of 85 % sterile, 10 % compost, 5 % manure, and fertilizer (R4) and 100 % sandy clay from intercalations (R5);
  - herbaceous species provided large amounts of D.M. in 100 % sterile material (R1 – mixture of sterile rocks from the dump, R5 – sandy clay from intercalations, and R6 – coaly marl from intercalations).
- comparing R4 with R3 (R3 lacks the fertilizer) significant plant growths were observed at a given moment during the experiment and the increase in D.M. in R4 which is explained by the use of fertilizer.

5. Conclusions

An increasingly studied and applied method for restoring fertility on mining dumps is represented by techniques for stimulating the pedogenesis process based on the dumped material itself instead of much more expensive and difficult to apply techniques that consist of the "import" of a topsoil layer (of different thicknesses depending on the intended use: agriculture, forestry, orchards, vineyards, etc.) often difficult to procure. Inert clay and clayey–sandy rocks represent a good base of inorganic matter for the reconstitution of topsoil when mixed with biodegradable organic matter and enriched with nutrients necessary for plant growth and life support.

The quick method for selecting plant species to accelerate pedogenesis on anthropogenic protosols was developed in the form of a logical scheme consisting in the 6 steps described in the paper.

The proposed logical scheme facilitates the understanding of how the soil is formed but also highlights the directions and interventions necessary to bring an anthropogenic protosol to an acceptable quality that supports the development of vegetation.

Improving the quality of anthropogenic protosols will allow the development of more and more varied and valuable types of plants, which will support the creation of strong, complex ecosystems, increase the value of land, and offer multiple possibilities for their reuse.

In general, sterile substrates had good and very good results, supporting the growth of the chosen species and achieving high productivity. The resulting plants can contribute to the enrichment of the substrate with organic matter in order to accelerate the pedogenesis process.

The proposed methodology can be applied in most cases of reclamation of waste dumps and/or degraded lands and represents a quick way to establish the species that can support the processes of improving their quality.

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