MONITORING THE DEVELOPMENT OF PLANTS ON THE ANTHROPOGENIC SOILS FROM THE STERILE DUMPS OF THE COAL OPEN PITS IN THE ROVINARI MINING BASIN

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Abstract. *Topsoil is a valuable resource, the only one capable of supporting vegetation development. The soil covering of the earth is called the pedosphere and is formed by the interaction between the other spheres: atmosphere, lithosphere, hydrosphere, and biosphere. Human actions produce minor to major changes in soil balance and can even cause its irreversible loss. In mining areas, as a result of the discovery of the deposit and the construction of waste dumps, extensive areas of degraded land appear, on which only the waste materials from the cover and intercalations are found, which lack the essential property of soil, namely fertility. These materials constitute the anthropogenic protosols, undeveloped soils in terms of the physical, chemical, biological, and pedological properties that define them. On anthropogenic soils in the early stages of their formation as fertile soil, it is necessary to apply some amendments to support the growth and development of vegetation and, in addition, it is recommended to establish so-called green crops to be incorporated into the soil as green fertilizers. Several plants are recommended as green fertilizers, which also have an ameliorative role, such as clover, grass, alfalfa, peas, etc. The research aimed to follow the development of different plant species on soil substitutes consisting of sterile material from the dumps and mixtures of sterile material, compost, cow manure, and fertilizers. Experiments were carried out in vegetation pots and were closely monitored from seeding to harvesting. For the rapid estimation of the population size for herbaceous plants, the method of squares using the DAFOR scale was applied. Also, a new method was proposed to estimate the degree/index of coverage of land surfaces by plants that can be easily applied at any time during the experiments.*

Keywords*: sterile dumps, anthropogenic soils, plant development, monitoring, methods*

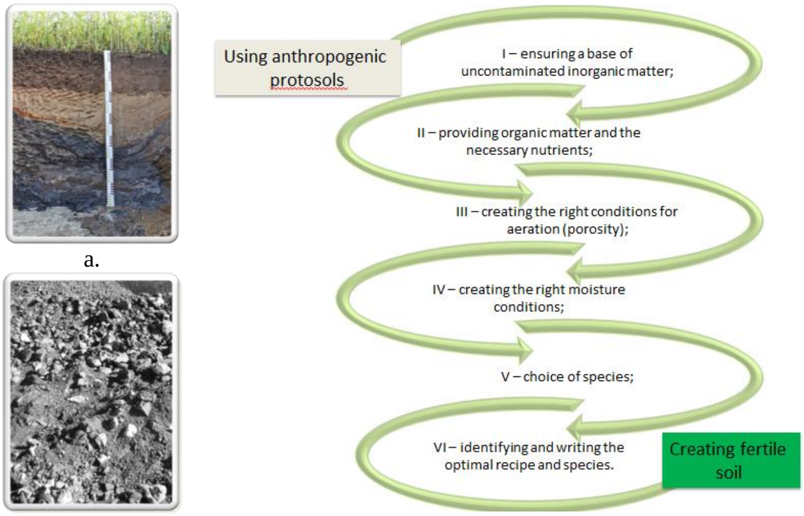
INTRODUCTION

The soil is the top layer of the earth which, under the action of the processes of bioaccumulation, alteration, and disaggregation, undergoes profound changes that make it an extremely useful resource, with its own properties, supporting life on earth. Five major factors control soil formation: climate, parent material, topography, time, and organisms (UGOLINI AND EDMONDS, 1983) (Figure 1.a).

On mining affected lands, the remaining lithological materials lack fertility and, in some cases, they contain dangerous elements (trace metals, radioactive elements, etc.). These materials constitute anthropogenic protosols (Figure 1.b).

When waste materials consist of inert rocks their conditions can be improved through amendments and proper works. They represent the inorganic matter. Organic matter content of the topsoil generally varies between 5 and 10 % and it is very important for the healthy and functions of the soil. In this sense, one of the main stages of supporting the formation of the topsoil is the enrichment of the inorganic matter with organic matter. In addition, it is necessary to ensure a balance between the porosity and moisture of the soil (Figure 1.c). (APOSTU ET AL., 2024b).

Although in low proportion and variable depending on the type of soil, 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 (GRAND AND MICHEL, 2020; DA SILVA ET AL., 2023; SCHULTE ET AL., 2014; BCSCD, 2017).



a. b. c.

Figure 1. a. Fertile soil; b. Anthropogenic protosols; c. Important stages in pedogenesis process

The quality and quantity of the topsoil is affected by numerous anthropic activities, but also by natural phenomena. Numerous researchers (TAROLLI ET AL., 2019; MOSIER ET AL., 2021; NUNES ET AL., 2020; DAZZI AND LO PAPA, 2015; MASSOUKOU PAMBA ET AL., 2023) are searching for solutions to restore soils on degraded lands, understanding their importance in maintaining ecosystems and climate in proper condition, ensuring land productivity, reducing the impact that humanity has on the environment through the continuous expansion, occupation, modification, and degradation of lands, etc.

MATERIAL AND METHODS

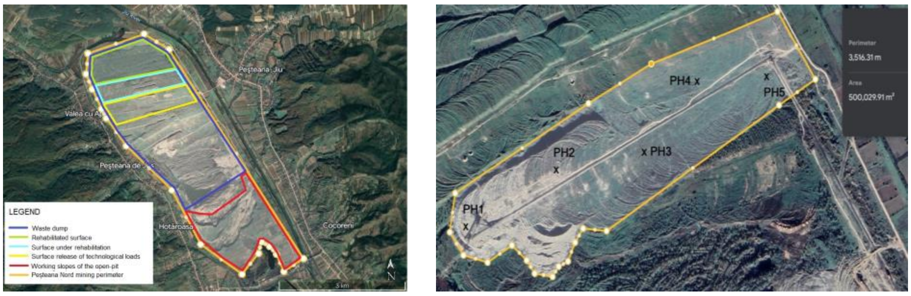
In the Rovinari Mining Basin, Gorj County, Romania, 18 internal and external waste dumps have been identified, belonging to 12 open-pit mines established over time. The waste rocks deposited in the dumps are similar throughout the Rovinari Basin, with the region's lithology consisting of clays, sands, and marls, along with various mixtures of these rock types (being inert, non-toxic, and non-hazardous sterile rocks). For this reason, the research focused specifically on the internal waste dump of the Peșteana Nord open-pit in the Rovinari Mining Basin.

The opening works for the Peșteana Nord open-pit began in 1980. It is estimated that lignite exploitation in this area will cease this year (2024) due to the depletion of the reserve within the licensed perimeter (***, 2019 - 2024).

The Peșteana Nord mining perimeter is located within the administrative territory of the Urdari and Bâlteni communes in Gorj County. The area is situated in the meadow area of the Jiu River, at altitudes ranging between 132 – 150 meters (SMEU, 2012).

Before reaching the base level of the open-pit, waste rocks resulting from opening works and lignite extraction were deposited in the external dump, after which the waste rocks were deposited further in the internal dump of the open-pit. The dump (constructed in 4 steps) is still in use, with some sections released of technological loads and others rehabilitated (Figure 2.a).

In order to conduct pot experiments, 5 samples of sterile rocks (PH1-PH5, from 0 to 20 cm depth, in a zigzag pattern) were collected from the second step of the internal dump of the Peșteana Nord open-pit (Figure 2.b), with the aim of creating representative blank samples through mixing.



a. b.

Figure 2. a. Peșteana Nord mining perimeter; b. Location of plot and sampling points on the dump (APOSTU ET AL., 2024b)

The materials used and the main experimental steps followed (APOSTU ET AL., 2024a):

1. Materials:
   a. Sterile rocks: PM1-4 (dusty sand with gravel elements - mixture of samples PH1-PH5), PM5 (sandy clay), PM6 (coaly marl);
   b. Compost enriched with activated carbon;
   c. Cow manure enriched with peat;
   d. Mineral fertilizer containing macroelements (13% N - 5% P - 24% K) and microelements (Fe, S, MgO, Mn, Zn, Cu, B);
   e. 30 pots (30 cm x 15 cm x 15 cm);
   f. Grass, alfalfa, red clover, and green peas seeds.
2. Steps:
   a. Establishing soil substitutes:
      - R1 = 100 % sterile material (blank sample PM1-4);
      - R2 = 90 % sterile material (PM1-4) + 5 % compost + 5 % manure;
      - R3 = 85 % sterile material (PM1-4) + 10 % compost + 5 % manure;
      - R4 = 85 % sterile material (PM1-4) + 10 % compost + 5 % manure + fertilizer;
      - R5 = 100 % sterile material (blank sample PM5);
      - R6 = 100 % sterile material (blank sample PM6);
   b. Establishing the plant mix for sowing:
      - S1 = 100% green peas;
      - S2 = 50 % red clover + 50 % grass / universal lawn;
      - S3 = 50 % alfalfa + 50 % grass / universal lawn.
   c. Preparing the vegetation pots (Table 1):

Table 1. The preparation of the vegetation pots and their labeling

Soil substitute/Pot no. / Plant species	R1		R2		R3		R4		R5	R6
	1	2	1	2	1	2	1	2	1	1
S1	S1R1	S1R1	S1R2	S1R2	S1R3	S1R3	S1R4	S1R4	S1R5	S1R6
S2	S2R1	S2R1	S2R2	S2R2	S2R3	S2R3	S2R4	S2R4	S2R5	S2R6
S3	S3R1	S3R1	S3R2	S3R2	S3R3	S3R3	S3R4	S3R4	S3R5	S3R6

d. Monitoring (monitoring of essential parameters, phenological determinations, monitoring of plants development and heights).
The soil substitutes were prepared by manual and mechanized mixing.
Experiment duration: approximately 3 months (94 days).

RESULTS AND DISCUSSIONS

During the experiments we have monitored soil pH, moisture, and degree of illumination in order to follow the state of the soil at a given time and to know what the best interventions are (Table 2 - limits of variation for the observation period day 1 – day 9).

Table 2.

Data regarding pH, moisture, and degree of illumination (APOSTU ET AL., 2024b)

Soil mixture	pH [pH units]	Moisture, w [%]	Lighting degree, E [lx]
R1	7.5	30 – 100	520 – 2000 (and > 2000)
R2	7.5	58 – 100	
R3	7.1 – 7.8	70 – 100	
R4	7 – 7.2	45 – 100	
R5	6.8 – 7.6	29 – 100	
R6	7.2 – 7.7	30 – 100	

w < 35 % dry soil; w = 35 – 75 % – moist soil; w > 75 % – wet soil; E → 0 – darkened; E → 2000 lx – illuminated; pH ≤ 3.5 – extremely acidic; pH = 3.6 – 4.2 – very strongly acidic; pH = 4.3 – 5 – strongly acidic; pH = 5.1 – 5.8 – moderately acidic; pH = 5.09 – 6.7 – slightly acidic; pH = 6.8 – 7.2 – neutral; pH = 7.3 – 8.4 – slightly alkaline; pH = 8.5 – 9.0 – alkaline; pH > 9 – strongly alkaline.

The seeding, germination, flowering, fruit growth, and maturity phases of plant development, were followed and studied and the corresponding dates were registered (Table 3).

Table 3.

Observations on phenological stages

Soil substitute / Stage	R1		R2		R3		R4		R5	R6
	1	2	3	4	5	6	7	8	9	10
Green peas										
Sowing	D1									
Germination	D12	D11	D11	D12	D12	D12	D10	D10	D9	D13
Flowering	D51	D51	D41	D41	D40	D41	D41	D41	D38	D54
Fruit growth	D59	D58	D54	D53	D52	D52	D51	D50	D48	-
Maturity	D94	-	-	D94	D94	D94	D94	D94	D94	-
Harvesting	D94									-
grass+red clover										
Sowing	D1									
Germination	D6	D7	D5	D5	D5	D5	D5	D6	D6	D5
Flowering	-	-	D93-D94	-	-	-	-	-	-	D90-D94
Fruit growth	-	-	-	-	-	-	-	-	-	-
Maturity	D94	D94	D94	D94	D94	D94	D94	D94	D94	D94
Harvesting	D94									
grass+alfalfa										
Sowing	D1									
Germination	D6	D6	D5	D5	D5	D5	D5	D5	D5	D5
Flowering	-	-	D92-D94	-	-	-	-	-	D89-D94	D89-D94
Fruit growth	-	-	-	-	-	-	-	-	-	-
Maturity	D94	D94	D94	D94	D94	D94	D94	D94	D94	D94
Harvesting	D94									

Green peas blooms 30-50 days after sowing, with the flowering phase lasting 10-25 days on a single plant. Physiological maturity is considered achieved when the pod dries, the green peas are wrinkled (although they may also be smooth), harden, and vary in color from shades of green to yellow. The green peas were harvested simultaneously with the other species, even though full maturity was generally not reached, as it was considered that the development stage was sufficient for analyses and drawing relevant conclusions.

Alfalfa, red clover, and grass are considered mature at two different times: during the flowering phase for hay production or when seeds reach maturity for seed production, depending on the desired primary product. The point of maturity signals the appropriate time for harvesting. Alfalfa, red clover, and grass were harvested when they were considered mature for most pots corresponding to green manure production (comparable to hay production, without focusing on seed production).

At the time of harvest, flowering of red clover and alfalfa was observed in only a few pots. Generally, alfalfa, red clover, and grass are harvested during the flowering phase when alfalfa reaches a height of 45–60 cm, red clover 30–60 cm, and grass over 30 cm. However, in this experiment, flowering occurred when the plants had grown taller than the theoretical heights, reaching 89–90 cm (for alfalfa and red clover). It is worth noting that the grass reached a maximum height of approximately 50 cm.

Population density, or population count, represents the number of individuals (organisms) per unit of area or volume. One of the most commonly applied methods for estimating population count is the squares method, which can be conducted through counting or estimation.

For herbaceous plants, where individual counting is impossible due to high density, population must be estimated, with the square-frame method using the **DAFOR** scale (D – dominant; A – abundant; F – frequent; O – occasional; R – rare) being the most practical (BATTES, 2018).

Figure 3 illustrates the working method for the squares technique using the DAFOR scale (the estimation method). Population density determination was carried out at three different times, specifically on days 14, 34, and 62 (Figure 3 and Table 4).

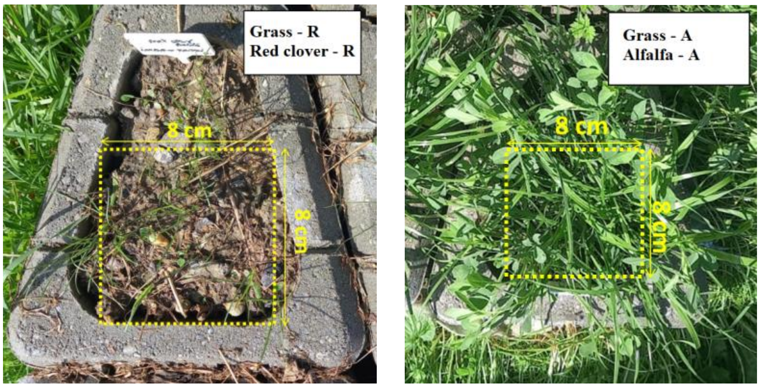


Figure 3. Application of the method of squares (8x8 cm); Soil subtitute R1, plant S2, day D14 - left; Soil subtitute R5, plant S3, day D34 - right

Although alfalfa emerged later in two of the pots and somewhat timidly in the others, it exhibited excellent growth towards the end of the experiment, being abundant in R1, R2, R3, and R5 and even dominant in R4 and R6.

In pot R4, a sudden and markedly accelerated growth was observed in the middle period of the experiment, a growth likely attributable to the fertilizer added to these pots.

Clover was abundant in R1-R5 and dominant in R6.

Table 4.

Determining the population density (DAFOR scale)

Soil substitute			R1		R2		R3		R4		R5	R6
Plants species		Pot no. / Day	1	2	3	4	5	6	7	8	9	10
S2	I	D14	O	O	O	O	O	O	O	O	F	O
		D34	D	A	A	F	F	F	F	A	A	A
		D62	D	D	D	D	D	D	A	A	D	A
	T	D14	R	-	O	O	O	R	O	R	O	F
		D34	R	O	O	A	F	O	F	F	A	A
		D62	A	A	A	A	A	A	A	A	A	D
S3	I	D14	R	O	O	O	O	R	R	R	F	F
		D34	F	D	A	F	F	R	F	A	A	A
		D62	D	D	D	D	D	D	A	A	A	A
	L	D14	R	-	O	O	O	-	O	O	F	F
		D34	F	R	F	A	O	-	F	A	A	A
		D62	A	A	A	A	A	A	D	D	A	D

I – grass; T – red clover; L – alfalfa; D – dominant; A – abundant; F – frequent; O – occasional; R – rare

Generally, grass was dominant in all pots where alfalfa and clover were abundant, and vice versa.

The degree/coverage index (I) of the ground surface by the plants foliar cover depends on the position, size, and shape of the vegetative elements and can be defined as the ratio between the area occupied by the vegetative elements (Sp) and the land area occupied by the crop/plantation (St). Four possible scenarios are defined:

- Sp = St → I = 1 (coverage degree = 100%)
- Sp > St → I > 1 (coverage degree > 100%)
- Sp < St → I < 1 (coverage degree < 100%)
- Sp → 0 → I < 1 (coverage degree → 0%)

This is a estimative method and is similar to the determination of the Leaf Area Index (L_{AI}). This index was determined only for herbaceous species. The soil coverage index was measured at four different times: on days 14, 34, 62, and 94 (Table 5).

Table 5.

Determination of soil coverage index

Soil substitute		R1		R2		R3		R4		R5	R6
Plants species	Pot no. / Day	1	2	3	4	5	6	7	8	9	10
S2	D14										
	D34										
	D62										
	D94										
S3	D14										
	D34										
	D62										
	D94										

coverage degree > 100%;coverange degree = 100%;coverage degree < 100%; coverage degree → 0 %;

A gradual, normal coverage was generally achieved two months after sowing, with the surfaces of all pots being at least 100% covered. The best development and the fastest substrate coverage were observed in soil substitutes R5 and R6.

Given that the square and coverage index methods could not be applied for the third species used in the experiment, namely green peas, their development was monitored through classic methods.

For green peas, the highest yield was obtained in soil substitute R5, a sandy clay, resulting in over a hundred pods and nearly 80 grams of healthy, partially dried seeds.

At first sight, good productivity was also obtained in soil substitutes R3, a mixture of clayey sand from the dump with 10% compost and 5% manure, yielding 50-60 pods per pot and 40-70 grams of seeds per pot. However, this soil subtitute presented the only cases of rotten pods and seeds (in considerable proportions, from 10 to 40%).

Soil substitute R1, composed of 100% sterile material from the dump, supported the production of about 50 pods per pot and 30-40 grams of seeds per pot. Considering that these are field conditions, the yield is acceptable.

CONCLUSIONS

The experiment was conducted in 30 vegetation pots using 3 species/ mixture of plant species and 6 soil substitutes based on sterile material from the Peșteana Nord internal dump.

Herbaceous plants monitoring (clover, alfalfa, grass) was performed using an existing method (the square method with the DAFOR scale) and a proposed one (the soil coverage index method).

Analyzing the population density, red clover was found to be abundant in the pots, even dominant in soil substitute R6. Although alfalfa showed slow development initially, it was found in abundance in 4 pots by the end of the experiment, and dominant in the other 2 (R4, R6). Grass was dominant in all pots where alfalfa and red clover were abundant and vice versa.

The highest coverage degree was observed in the grass and red clover mixture, as well as the grass and alfalfa mixture in soil substitutes R5 and R6.

Green pea monitoring was conducted by registering germinated seedlings and their height throughout the experiment. In R6, although germination was at 50%, the seedlings wilted due to a moderately saline substrate, a condition not tolerated by green peas.

Overall, plant development was generally acceptable, with phenological stages being reached within theoretically expected periods, except in a few cases where stages were delayed due to relatively poor substrates.

Vegetation was harvested on day 94, when maturity was reached and the degree of development was considered sufficient. After harvesting stage, studies on plant size revealed the following: plants showed certain preferences; for example, green peas developed best in soil substitute R5, a sandy clay, while the other species developed well in several pots (grass + red clover in R1, R5, R6, and grass + alfalfa in R4, R5, R6); red clover and alfalfa grew better in slightly alkaline soils, as confirmed by plant size at harvest; green pea seeds had a germination capacity of approximately 30-60% (in two soil substitutes, namely R1 and R2, reaching only 10-20%).

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