CONTRIBUTIONS TO THE PLANT ASSORTMENT FOR THE ECOLOGICAL RESTORATION OF SLAG AND ASH DUMPS FROM LIGNITE-FIRED POWER PLANTS

Teodor MARUŞCA[1] Lucian DINCĂ[2] Radu BREJEA[3]

[1,2] Research-Development Institute for Grassland Braşov, 5, Cucului Street, 500128, Braşov, Romania
[3]University of Oradea, Faculty of Environmental Protection, 26 General Magheru St., 410048 Oradea, Romania
[3]Academy of the Romanian Scientists, 1 Ilfov Street, Bucharest, 030167, Romania

RESEARCH ARTICLE

Abstract
The paper presents several new principles for approaching the restoration of vegetation on slag and ash dumps from lignite-fired power plants, in which the biotic factor is maximally activated. Only where rainwater and wind erosion cannot be controlled are construction elements (masonry, gabions, small fences, geogrids, geotextiles, and other combinations) used, with outcomes that are more or less biological. The results obtained on a 15-hectare dump site at Sânpetru, Braşov—a Romanian priority in this field—are presented. After three years of experimentation, the best results for renaturation on a eutrophic peat substrate were achieved with the grass species Bromus inermis, Onobrychis viciifolia, Phalaris arundinacea, Arrhenatherum elatius, Dactylis glomerata, Melilotus albus, M. officinalis, and Lotus corniculatus; with the shrub Amorpha fruticosa; and with the tree Robinia pseudoacacia, fertilized appropriately with 150 kg/ha N, 75 kg/ha P_2O_5, and 75 kg/ha K_2O. These results have been successfully applied further in the ecological reconstruction of this type of dump.

Keywords: *slag and ash dumps, ecological reconstruction, plant assortment*
#Corresponding author: maruscat@yahoo.com

INTRODUCTION

The slag and ash dumps resulting from coal combustion in thermal power plants are a major source of pollution of the air, soil, and surrounding vegetation if no measures are taken to restore them. (HARRIS et al., 1996; MARUŞCA et al., 1998; CĂPITANU et al., 1999; DUMITRU et al., 1999; MARUŞCA & DINCĂ, 2000)

The total area of such dumps originating from the 26 coal-fired power plants in our country covers 2,638 hectares. (DINCĂ et al., 2001)

The Braşov Combined Heat and Power Plant (CET Braşov) operates in cogeneration mode and is primarily intended to supply thermal energy (in the form of steam and hot water) to industrial consumers in the Braşov North area, as well as to urban consumers connected to the Braşov North district heating system (residential areas of Braşov Municipality), and to produce electrical energy. (CONSTANTINESCU et al., 1999)

The main equipment and installations of the power plant are:

- Two steam boilers of 420 t/h operating on lignite as the primary fuel and natural gas as a support fuel (for ignition and flame stabilization);
- Two turbo-generator units of 50 MW each, both in condensation mode with adjustable DSL–50 type bleedings;
- Equipment and installations for fuel handling (solid and gaseous), hydraulic disposal of slag and ash, chemical water treatment, and district heating systems located within the plant premises;
- Electrical and automation systems and installations.

CET Braşov was initially designed to operate on lignite from the Oltenia coal basin, with a lower calorific value of approximately 1,550 kcal/kg, but ultimately used lignite from closer coal basins such as Baraolt, Filipeştii de Pădure, Câmpulung Argeş, and Borsec.

For boiler ignition and flame support, natural gas—with a calorific value of 8,500 kcal/Nm^3—is used as an auxiliary fuel, accounting for about 10% of the total fuel consumption at nominal load.

As a result of the fuel combustion process, slag and ash are produced as waste, which are hydraulically transported through pipelines to a specially designed dump site located at the foot

of Lempeș Hill, about 12 km from the plant, in Sânpetru commune.

The slag and ash dump of CET Brașov underwent two main stages of development:

- The initial dump, designed for a maximum height of 15 m and a final capacity of about 2,300,000 m^3, which is currently completely filled, with one last height increase of about 4 m planned;
- The new dump, built immediately adjacent to the initial one, with the first section commissioned in 1998 and a final capacity of about 3,500,000 m^3.

The paper presents several new aspects and results regarding the ecological restoration of these polluting waste dumps, developed by the Research and Development Institute for Grasslands – Brașov, the Forest Research and Management Institute (ICAS) – Brașov Station, and the Transilvania University of Brașov, in close collaboration with the Institute for Energy Studies and Design (ISPE) – Bucharest (general designer) and the beneficiary CET Brașov, aiming ultimately to:

- control water and wind erosion;
- initiate and accelerate pedogenesis processes after the establishment of herbaceous vegetation;
- enable deep stabilization of the substrate by woody vegetation;
- ensure long-term consolidation of the entire site after shaping the slag and ash and covering them with a vegetative layer (eutrophic peat), through successive stages—grass establishment, shrub planting, and afforestation—either partially or entirely, as the final stage of the investment;
- encourage the appearance and spread of microorganisms, insects, and other organisms in the biogeochemical chain of the newly formed ecosystems;
- provide economic (fodder, timber, etc.), aesthetic (landscape restoration), and recreational (tourism, sports, e.g., golf courses) functions on lands currently occupied by such waste deposits.

MATERIAL AND METHOD

Research activities aimed at achieving the proposed objectives were carried out in the field on four experimental plots, each with an area of 2,500 m^2, located on the main exposures (S, E, N, W) of the first ash dump. After shaping the slopes to an inclination of about 30°, a 15–20 cm thick layer of eutrophic peat from a nearby area was applied.

Part of the research was conducted in MITSCHERLICH-type vegetation pots in the ICDP Brașov micro-greenhouse, while agrochemical analyses of the substrate were performed at OSPA Brașov, following the current methodology.

Initially, several types of slag and ash from coal-fired power plants in Oradea, Timișoara, and Doicești-Dâmbovița were studied and compared with those from CET Brașov, in order to determine the degree to which the research results could later be generalized.

In the experimental plots, during May, a mixture of grasses (15 species of grasses and 8 legumes) was sown at a rate of 160 kg/ha, on a uniform agrochemical base of 75 kg/ha phosphorus and three nitrogen doses (0, 75, and 150 kg/ha), both with and without protective plants (35 kg/ha spring barley + 35 kg/ha rye + 10 kg/ha millet).

On the edges of the slopes within the experimental plots, English-made geogrids were installed to provide additional stabilization of the substrate.

The assortment of shrubs and trees was planted in November within the experimental plots and in April on the dump crest.

In addition, various other herbaceous and woody species were sown and planted to complete the assortment of plants used for vegetation restoration on this type of dump.

During this period, numerous observations and measurements were carried out, as follows:

- evolution of the floristic composition of the grass cover;
- biometric measurements on woody plants;
- planting losses among woody species;
- degree of propagation and spread through rhizomes, stolons, and root suckers of certain herbaceous and woody species;
- routine agrochemical analyses of the substrate (ash + peat) to a depth of 0–30 cm.

Given the novelty of the topic, several techniques and methods from grassland cultivation and forestry on light (sandy) soils were adapted.

The climatic conditions of the area where the dumps are located, according to data from the Bod weather station (508 m altitude), are typical of an intracarpathian depression, with an average annual temperature of 7.8°C, an average January temperature of –5.3°C, and Romania's absolute minimum temperature of –

38.5°C (recorded on January 25, 1942). The average July temperature, the warmest month, is 18.0°C, with an absolute maximum of +37.2°C (September 9, 1946), resulting in an absolute temperature amplitude of 75.7°C, one of the highest in the country.

The average number of summer days (with temperatures above 25°C) is 67, and that of tropical days (above 30°C) is 14 days.

Average annual precipitation is about 680 mm, with large year-to-year fluctuations (1,060 mm in 1912 and 383 mm in 1950) and between seasons, often accompanied by periods of drought.

Under these conditions, the primary vegetation consisted of oak (Quercus robur) and sessile oak (Q. petraea) forests, interrupted by valleys and wet eutrophic meadows, on which the Sânpetru–Brașov dumps were established, near the Cișmac stream, a tributary of the Olt River.

RESULTS AND DISCUSSIONS

Following the agrochemical analyses, it was found that the pH in H_2O of the different ash samples is around 8.2 (slightly alkaline), with deviations of ± 0.2–0.3, making them very similar in this respect (Table 1).

Table 1

Agrochemical quality of different slag and ash samples from various coal-fired power plants in Romania

Specification	Unit	1.Brașov		2.Doicești DB		3.Timișoara		4.Oradea		Average Value	Aprec. Agro-ch.
		Value	Diff.	Value	Diff.	Value	Diff.	Value	Diff.		
PH in H_2O	ind.	8.0	-0.2	8.2	0	8.0	-0.2	8.5	+0.3	8.2	Slightly alkaline
$CaCO_3$	%	4.0	+1.9	0.8	-1.3	1.3	-0.8	2.2	+0.1	2.1	Medium
Humus	%	1.04	-0.66	1.16	-0.54	3.19	+1.49	1.39	-0.31	1.7	Low
N Index	ind.	1.04	-0.66	1.16	-0.45	3.19	+1.49	1.39	-0.31	1.7	Low
P-AL	ppm	91.0	-9.5	118.0	+17.5	111	+10.5	82.0	-18.5	100	-
Corrected P-AL	ppm	46.4	+1.3	48.5	+3.4	56.6	+11.5	28.7	-16.4	45.1	High
K-AL	ppm	286	+11.0	242.0	-33.0	306	+31	266	-9.0	275	High

As expected, the potassium content is relatively high, averaging 275 ppm, with maximum deviations of ±30 ppm.

Surprisingly, the phosphorus content is also high, averaging 45 ppm, with the richest ash sample in this element coming from Timișoara (56.6 ppm), and the poorest from Oradea (28.7 ppm).

The very good supply of these two fertilizing elements (P and K) is extremely important for the establishment of vegetation, especially for species in the legume family, which are nitrogen-fixing plants.

The $CaCO_3$ content averages 2.1% (ranging from 0.7% at Doicești to 4.0% at Brașov) and also plays an important role in the establishment of legumes.

The nitrogen content in the ash is very low; therefore, this element must be applied obligatorily on this type of dump until the protective grass cover is established.

Regarding the success of the seed mixtures used for vegetation restoration on these dumps, after three years, out of 25 species sown, 12 species successfully established, including 6 perennial grasses, 5 perennial legumes, and 1 shrub (Table 2).

Table 2

Influence of vegetation factors on the floristic composition of mixtures used for the anti-erosion protection of slag dumps at Sânpetru–Brașov

Species	Average 1999-2000	Exposure		Fertilisation			Cereals	
		Sunny	Shaded	kg/ha			kg/ha	
				0	75	150	0	80
A. Grasses	**69**	**73**	**65**	**55**	**69**	**81**	**71**	**67**
Bromus inermis	29	36	22	23	30	34	30	28
Phalaris arundinacea	17	16	18	13	15	21	17	17
Arrhenatherum elatius	12	13	11	10	12	14	12	12
Dactylis glomerata	9	5	13	9	9	9	9	9
Festuca pratensis	1	1	1	+	1	2	1	1
Phleum pratense	1	1	+	+	2	1	1	+
Other grasses	+	+	+	+	+	+	+	+
B. Legumes	**31**	**27**	**35**	**45**	**31**	**19**	**29**	**33**
Onobrychis viciifolia	17	18	16	20	18	13	19	15
Melilotus albus	5	3	7	9	5	2	3	7
Melilotus officinalis	3	3	3	4	3	2	3	3
Lotus corniculatus	2	1	5	7	3	1	2	4
Trifolium hybridum	2	1	3	3	1	1	1	3
Other legumes	1	1	1	2	1	+	1	1
C. Shrubs	+	+	+	+	+	+	+	+
Amorpha fruticosa	+	+	+	+	+	+	+	+

Among the grasses, the best-performing species was smooth brome (bromus inermis), followed by reed canary grass (phalaris arundinacea), tall oatgrass (arrhenatherum elatius), and orchard grass (dactylis glomerata). among the legumes, the top performers were sainfoin (onobrychis viciifolia), followed by white and yellow sweet clover (melilotus albus, m. officinalis) and bird's-foot trefoil (lotus corniculatus).

While some of these species are commonly propagated for fodder (brome, orchard grass, sainfoin, and bird's-foot trefoil), others are not regularly cultivated in romania (reed canary grass, tall oatgrass, white and yellow sweet clover), making it necessary in the future to produce seeds of these perennial grass species.

The success of the grass mixture is determined by vegetation factors, among which the substrate and its properties play a particularly important role. the powdery material with low water retention is improved by undecomposed organic matter and the water-holding capacity of the eutrophic peat, ultimately creating an aerohydric regime close to optimal for plant growth and development.

on sunny exposures, brome and sainfoin dominate, while on the shaded slopes of the dump, reed canary grass, white sweet clover, and bird's-foot trefoil—more moisture-loving species—participate more actively.

Nitrogen fertilization stimulates perennial grasses (55–81%) but reduces the participation of legumes (45–19%), a pattern similar to that observed in sown grasslands.

Regarding the presence of cereal crops in the mixture, their protective role is noteworthy, as they shield young perennial grass plants from large fluctuations in moisture and strong insolation, characteristic of the slopes of these dumps.

An interesting achievement is the successful establishment of dwarf japanese false indigo (amorpha fructicosa) from seeds, despite strong competition from perennial grasses. after three years of growth, the japanese false indigo reaches an average stem diameter of 5 mm (range 1–10 mm) and a height of 26 cm (range 12–55 cm) in the unharvested vegetation cover.

Similarly, in the future, black locust (Robinia pseudoacacia) could be introduced into these mixtures. it has also grown from seeds accidentally brought with river ballast, reaching after three years an average diameter of 18 mm (range 10–30 mm) and a height of 152 cm (range 100–175 cm) on areas with sparser grass cover, which favored its development.

The introduction of shrub or even tree seeds into ecoprotective grass mixtures is a romanian priority in this field, which will revolutionize the current strategy and system for the ecological reconstruction of dumps.

Regarding the success of planting shrub and tree species, some differences are observed between species (table 3).

Table 3

Seedling dimensions and losses recorded in the second year after planting on the ash dumps at Sânpetru–Brașov

Species	Exposure						Average		
	Sunny			Shaded					
	Diameter	Height	Losses	Diameter	Height	Losses	Diameter	Height	Losses
Wild rose	5	49	6	5	40	7	5	45	6
Flowering ash	10	59	6	12	61	8	11	55	7
Honey locust	8	45	7	5	42	9	7	44	8
Hawthorn	9	45	8	10	43	6	11	44	7
Black locust	13	83	-	9	112	-	16	97	-
Russian olive	16	115	-	-	-	-	16	115	-
Poplar	16	130	-	15	132	-	6	131	-
Wild service tree	5	38	-	6	46	-	-	42	-
Average	-	-	7	-	-	7	-	-	7

The best-performing species are Russian olive (*Eleagnus angustifolia*) and flowering ash (*Fraxinus ornus*), followed by wild rose (*Rosa canina*) and hawthorn (*Crataegus monogyna*).

Notably, the seedlings of black locust (*Robinia pseudoacacia*), honey locust (*Gleditsia triacanthos*), wild service tree (*Sorbus torminalis*), and even poplar (*Populus nigra*) also performed well.

In general, on sunny exposures, woody species exhibit larger diameters, while on shaded exposures, seedlings tend to have greater height.

The dimensions (diameter and height) recorded for the seedlings indicate that they perform surprisingly well under the very difficult soil and climatic conditions—including the excessive drought experienced this year—typical of the region and the slag and ash dumps.

officinalis, and Lotus corniculatus, while the woody species from seed are the shrub Amorpha fructicosa and the tree Robinia pseudoacacia.

Planting allows the establishment of a wider assortment of shrubs and trees, among which the most notable are sea buckthorn, Russian olive, flowering ash, wild rose, hawthorn, honey locust, wild service tree, poplar, and others.

CONCLUSIONS

Mixtures of perennial grasses, cereals, shrubs, and trees, together with chemical fertilizers, can be formulated and applied just once on the dumps to restore vegetation for the purpose of reducing soil erosion.

On slag and ash dumps covered with eutrophic peat, the best-performing perennial grasses are: Bromus inermis, Onobrychis viciifolia, Phalaris arundinacea, Arrhenatherum elatius, Dactylis glomerata, Melilotus albus, M.

REFERENCES

Căpitanu, V., M. Dumitru şi colab., 1999: Impactul emisiilor termocentralelor asupra mediului ambiant, Recultivarea haldelor de cenuşă, Ed. “Risoprint”Cluj Napoca;

Cristea V. şi colab., 1990: Reconstrucţia ecologică a haldelor de steril minier, Contribuţii Botanice, pag. 33-37, Cluj Napoca;

Dumitru M., Gh. Blaga şi colab., 1999: Recultivarea terenurilor degradate de exploatările miniere din Bazinul Carbonifer Oltenia, Casa de editură “Transilvania Press” Cluj Napoca;

Filip (Tod) Monica, Marusca T., 2009: Results regarding to promovation in crop of *Phalaris arundinacea* cultivars, for production of forage and biomass, Eucarpia 2009 Conference INRA, XVIII-th Meeting of the Eucarpia Fodder Crops and Amenity Grasses La Rochelle – Franţa, Book of Abstracts, 11-14 mai, pp.75

Filip (Tod Monica) , 2011 : Contribuţii la extinderea în cultură pentru furaj şi biomasă a speciei *Phalaris arundinacea* L. în condiţii extreme de umiditate, Teza de doctorat, Facultatea de Agricultură, Universitatea de Ştiinţe Agricole şi Medicină Veterinară a Banatului, Timişoara

Harris, A.J., P. Biroh, J.P. Palmer, 1996: Land restoration and reclamation, Wesley Longman Ltd., Singapore;

Jordan III, W.R., M.E. Gilpin, J.D. Aber, 1997: Restoration ecology, a syntetic appreoch to ecological research, University Press, Cambrige, UK.

Maruşca T., Maruşca Letiţia Felicia, 1985: Consideraţii privind introducerea în cultură a speciei *Typhoides arundinacea* (L) Mnch pentru producerea de furaje, Revista de creştere a animalelor, nr.6, pag.24-30, Bucureşti.

Maruşca T., Blaj V.A., Zevedei P.M., Brejea R.P., Petreanu Antoanela, Bârlădeanu B., Rogojan C., 2020, Contribution to restoration of waste dumps of sulfur from the Călimani Mountains, Annals of the University of Oradea, Fascicle: Enviromental Protection, doi. org/10 528 1/Zenodo. 4362296, vol. XXXIV.

Samfira I., 2001, Cercetări privind biologia şi ameliorarea speciei *Phalaris arundinacea* L., Teză de doctorat, USAMVB Timişoara.

.