Strategies for Covering Fly Ash Dumps with Plant Species Suitable for Phytostabilization

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Abstract

In the context of the revegetation of fly ash dumps, the strategy chosen is very important in order to obtain a vegetal layer that quickly and efficiently covers the fly ash dump, as well as, to allow the wildlife habitat development. The strategy must include: adequate treatments by incorporating fertilizer and amendments, as composts and modified indigenous volcanic tuff; selecting plant species and agricultural work in accordance with geographical and weather conditions. Our *in situ* experiment on a lignite fly ash dump was performed in the fall during the seeding period of *Festuca arundinacea* and *Onobrychis viciifolia* species to provide the water requirement of plants, and consequently a quick and efficient development of plants, enabling them to resist later in the hot and drought days of summer. Among the seeding species, *Festuca arundinacea* adjusted more easily in the experimental variants. In this case, the treatment with biosolids and modified indigenous volcanic tuff can reduce the metal bioaccumulation, especially Pb (with 84-94%), Fe (with 53-63%) and Cu, Cr and Ni (between 12-53%). The other plant species did not tolerate the unfertilized fly ash. The fertilizer and modified indigenous volcanic tuff provided establishing conditions for the plant supplying the nutrients. Metal transfer to aerial tissues was reduced compared to control by 29.5-59.3% in the case of Cu, Cr, Ni and ranged 50-66% for Pb. Limiting the transfer of heavy metals in plant tissues is in accordance with a healthy habitat for the wildlife.

Keywords: heavy metals, vegetal layer, metal-tolerant plant species, bioaccumulation

1. Introduction

Over the last 30-40 years, ground coal combustion in thermal power generating plants from several cities in the Western Romania led to the formation of large deposits of waste including combustion residues, in particular ash and slag. Deposits cover large areas of land including farmland and interact with the environment in numerous ways such as:
deflation and erosion phenomena in which solid particles are scattered in surrounding areas; washing of soluble components with water from precipitations, in particular metal species, which are subsequently subjected to percolation and leaching; installation, on deposit protection dikes (consisting of soil mixed with ash and tamped), of various weed species that invade these areas and pose a danger for the surrounding crops. Numerous studies on the concentration of metals in ash indicate the presence of: Cr, Cu, Pb, Zn, Ni etc. in tens of mg/kg D.M., Mn and Fe in hundreds and thousands of mg/kg D.M. and sometimes Cd, As, B etc. [1, 2, 3]. These metals accumulate in plant tissues and cause adverse consequences to the ecological systems [4, 5].
To reduce the negative effects of immediate and long-term deposits of ash on the environment,

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they need to be stabilized by vegetation [6, 7, 8]. Ash deposits contain small amounts of carbon derived from lignite but it is difficult for plants to use that energy, or it is even inaccessible for plants. In addition, these deposits do not have the basic nutrients based on N and P required for plant development. Soil mixed with ash normally allows the development of some plant species that adapt easily to hard environmental conditions and often invade the land. These species are dangerous; a threat for the neighbouring crops that can be easily invaded.

For these reasons, the selection of plants must meet two important conditions: to be safe for agricultural areas (crops) and for animals that come to colonize the ecological zone and to cover the slag store. [9]

Vegetation strategy occupies an important place in land preparation by adding the fertilizers. Having regard the primary purpose of binding store and restore landscape, land is covered with soil and fertilized with mud resulted from a neighbouring station. The biosolids used for fertilization of the ash layer supply the minimum necessary of N and P compounds and have a reduced capacity to retain water in the soil. The addition of water maintaining materials, with porous structure, such as volcanic tuff, is a solution that allows, in periods of rainfall, to retain excessive water and gradually release it during the drought season as plants need it [10, 11, 12, 13].

Agricultural works carried out to form a layer of vegetation covering the ash are common and are aimed to ensure the incorporation of fertilizers and other additives for improving the ash characteristics in the upper layer that will be seeded, and, *in fine*, to harvest the plants if necessary etc.

From our previous studies we observed that very hot summers and prolonged droughts dry plants. Plants germinate and cover land cultivated by 45% and do not tolerate a scorching dry season. To prevent that, winter crops sown in September are initiated immediately after plowing the land. Plants germinated ca 70-80% and covered the land, resisting over winter. Development under winter conditions resulted in obtaining a compact coating plants prepared for hot days and drought in summer.

Plant species used in this study are *Festuca arundinacea* and *Onobrychis viciifolia*. These forage plant species are known to be tolerant to high concentrations of heavy metals in soils and can grow on such land.

Sprouting and tolerance of both species and, accumulation of six metals in tissues of the aerial plant parts was evaluated in this study. The applied vegetation strategy was with regard to a lower impact of the vegetation ecosystems installed on the habitat area, and the maximal limitation of pollutant transfer from the deposit.

2. Materials and methods

The study was performed on an *in situ* experimental block of fly ash dump consisting of 10 m^2 lots in three replicates. Ash did not contain excessive amounts of toxic heavy metals, but had the impediment of its specific structure of topsoil, hindering the proper root development and thus, of the upper parts of plants, because there is no sufficient water retention.

The experimental lot was fertilized with 5 t of D.M./ha of biosolids.

The biosolids (municipal sludge, anaerobically stabilized with macronutrients N, P compounds) fertilization was performed according to Rauta & Carstea (1983), who estimated that biosolids addition can increase with 15% the crop production. A 1 to 1.5 cm thin layer of municipal sludge was spread over the experimental lots (the municipal sludge from the sewage water treatment plant of Timisoara was black and with 95% humidity). Characteristics of biosolids: humidity = 95%, organic matter = 26.4%, N_{total} = 0.7%, P = 0.65%, pH = 6.1 [14].

The amendments used in the experiment were volcanic tuff (zeolite, with about 70% clinoptilolite) and a modified volcanic tuff (volcanic tuff was milled and mixed with water). The volcanic tuff and the obtained suspension of tuff in water was spread on the experimental field in the amount of 2 t DM/ha [15].

The experimental variants are as follow: Control - fly ash with soil; E1 - fly ash with soil and volcanic tuff; E2 - fly ash with soil and modified volcanic tuff; E3 - fly ash fertilized biosolids and volcanic tuff; E4 - fly ash fertilized biosolids and modified volcanic tuff.

Two plant species were cropped: *Festuca arundinacea* and *Onobrychis viciifolia*.

Soil sample analysis was done to determine the total iron, manganese, zinc, copper, chrome, nickel and lead quantities according to the ISO

11047/99 analysis method. Soil sample preparation for analysis was done in accordance with ISO 11464/98. Dried soil samples were digested with aqua regia. Analysis of metal accumulation in the aerial parts of plants was done on dried and, digested with concentrated hydrochloric acid, plant tissues. Plant sampling was done in accordance with the methodology described in STAS 9597/1-74, and sample analyse were done in accordance with STAS 9597/17-86. Plant and soil extract analysis was done using a spectrophotometer with atomic absorption (Varian Spectra AAS). The detection limit of the device is 0.001 mg/l. The land was sowed in September and analyzed in December when the examined plants had a height of 10-15 cm and coverage of 50-60% for *Festuca arundinacea* species and 30-40% for *Onobrychis viciifolia* species.

3. Results and discussion

Table 1 presents the metal concentrations in the experimental soils. The top layer that is a support for plant growth contained between 1,840-1,910 mg Fe/kg D.M.; 54.7 to 122.7 mg. Zn/kg D.M.; 63 to 81.6 mg Cu/kg D.M.; 53.9-97.7 mg Cr/kg D.M.; 51 to 70.7 mg Pb/kg D.M. and 6.9 to 10.6 mg Ni/kg D.M.

The results of the experiment show that both plant species germinated and grew in all the experimental variants, except that *Festuca arundinacea* seedlings were more vigorous and had an abundance 2-3 times higher than those of *Onobrychis viciifolia*.

It is known that plants accumulate different quantities of metals in their aerial tissues.

Tables 2 and 3 shows variation of accumulation of metals in aerial parts of *Festuca arundinacea* caused by treatment of the topsoil.

The addition of the volcanic tuff in both variants resulted in an increase in osmotic flow of metals to plant tissues and thus increased the amount of bioaccumulated metals up to 1.75 times the amount accumulated in plants grown on the control soil, as shown in Table 2. By adding biosolids and tuff the heavy metals uptake in the aerial tissues of *Festuca arundinacea* was reduced.

Table 1 - Metal content of topsoil in the experimental variants. Collected samples were from 0-5 cm depth. L1 - *Festuca arundinacea*, L2 - *Onobrychis viciifolia*

Experimental lot	**Concentration of metals in soil (mg/kg D.M.)**					
	Cu	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Fly ash - Control L1	64.2	72.4	1,860	52.6	7.0	54.7
Fly ash - Control L2	77.6	93.5	1,903	68.8	7.4	68.6
Fly ash + volcanic tuff L 1	70.9	77.6	1,868	58.2	7.4	70.9
Fly ash + volcanic tuff L 2	73.5	75.4	1,870	55.3	8.0	64.7
Fly ash + modified volcanic tuff L 1	70.6	80.6	1,875	54.7	10.3	84.7
Fly ash + modified volcanic tuff L 2	79.7	74.7	1,871	51.0	7.6	92.4
Fly ash + biosolids + volcanic tuff L 1	71.6	83.9	1,841	54.5	9.0	122.7
Fly ash + biosolids + volcanic tuff L 2	83.0	88.9	1,890	60.1	7.3	79.5
Fly ash + biosolids + modified volcanic tuff L 1	81.6	72.4	1,910	52.1	6.9	62.2
Fly ash + biosolids + modified volcanic tuff L 2	79.6	97.7	1,892	70.7	10.6	79.6

Table 2. Concentration of metals accumulated in *Festuca arundinacea* aerial parts harvested from the experimental lot of the ash dump (mg/kg D.M.)

Experimental lot	**Concentration of metals accumulated in *Festuca arundinacea* (mg/kg D.M.)**					
	Cu	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Control	19.20	9.7	1185.0	7.20	26.4	39.5
Fly ash + volcanic tuff	21.20	14.6	1,379.3	7.65	43.2	45.6
Fly ash + modified volcanic tuff	11.14	16.9	1,514.2	9.50	20.2	41.4
Fly ash + biosolids + volcanic tuff	15.02	4.9	559.9	4.10	7.03	29.5
Fly ash + biosolids + modified volcanic tuff	16.20	4.5	436.2	5.20	1.52	39.2

The addition of biosolids in association with volcanic tuff resulted in a drastic decrease in the amount of heavy metals accumulated in *Festuca arundinacea* plant tissues. Table 3 shows that Pb was accumulated from 73.4 to 84% less than the amount accumulated in plant tissues harvested from the control group, while Cr, Fe and Ni was 42.5 to 63% less.

The treatment has a lower efficiency from 12.5 to 29.2% for copper, and has no influence on zinc mobility. The modified volcanic tuff addition has a greater influence on diminishing the flow of metals to plant tissues than the unmodified tuff addition with biosolids fertilizers (Table 3).

Table 4 shows variations of metal accumulation in *Onobrychis viciifolia* tissues due to treatments performed on the ash layer.

The addition of biosolids in association with volcanic tuff in both variants resulted in a significant reduction in transfer of heavy metals to *Onobrychis viciifolia* plant tissue.

Table 5 shows the reduction of the concentrations of metals accumulated in *Onobrychis viciifolia* plant tissues and the concentrations accumulated in the same parts of the plants harvested from the control land.

The changes due to the addition of tuff and those produced by the mixture of volcanic tuff in the biosolids with two unmodified and modified versions can be observed in Table 5. Complex treatment with biosolids and volcanic tuff decreased the level of accumulated lead up to 60% and the Cr, Fe and Ni decreased up to 54.7 to 69.8%. The accumulation of Cu decreased only with 29.5-34.3% and zinc mobility was not affected by the combined treatments with biosolids and volcanic tuff.

The comparison between the levels of metals accumulated in both species suggested that leguminous plants may accumulate higher amounts of metals then grass species.

Table 6 shows a higher degree in accumulation of metals in *Onobrychis viciifolia* than in *Festuca arundinacea* harvested under similar conditions from the experimental ash dump. *Onobrychis viciifolia* had an increased affinity for certain metals such as Cu, Fe and Zn, irrespective of the ash treatment applied, but the other metals analyzed had less conclusive results.

Table 3. Reduction of metals accumulation from the experimental unit ash dump compared to control for *Festuca arundinacea*

Experimental lot	Reduction of metals accumulation in harvested plants from the experimental unit ash dump compared to control (%)					
	Cu	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Fly ash + volcanic tuff	-	-	-	-	-	-
Fly ash + modified volcanic tuff	40.6	-	-	-	-	-
Fly ash + biosolids + volcanic tuff	29.2	49.4	52.7	42.5	84	-
Fly ash + biosolids + modified volcanic tuff	12.5	53.6	63.0	27.7	94.0	-

Table 4. Concentration of metals accumulated in *Onobrychis viciifolia* harvested from the experimental ash dump mg/kg D.M.

Experimental lot	Concentration of metals acumulated in *Onobrychis viciifolia* (mg/kg D.M.)					
	Cu	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Control	28.3	11.7	3,066	10.2	11.79	64.9
Fly ash + volcanic tuff	29.7	6.59	1,751	12.1	5.95	48.2
Fly ash + modified volcanic tuff	24.9	-	2,346	6.8	5.19	48..8
Fly ash + biosolids + volcanic tuff	18.6	5.3	960.7	6.9	5.59	58.12
Fly ash + biosolids + modified volcanic tuff	19.8		923.5	4.15	4.7	57.6

Table 5. Reduction of metal accumulation in plants harvested from the experimental lots compared to the control for *Onobrychis viciifolia*

Experimental lot	**Reduction of metal accumulation in plants harvested from the experimental lots compared to the control for *Onobrychis viciifolia* (%)**					
	Cu	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Fly ash + volcanic tuff	-	43.6	42.8	-	49.6	26.1
Fly ash + modified volcanic tuff	7.0	-	23.4	33.2	56.0	26.3
Fly ash + biosolids + volcanic tuff	34.3	54.7	68.8	32.4	60.0	-
Fly ash + biosolids + modified volcanic tuff	29.5	-	69.8	59.3	52.5	-

Table 6. Metal accumulation rate in *Onobrychis viciifolia* compared to *Festuca arundinacea* harvested from similar variants of the same experimental lot located on the ash dump

Experimental lot	Metal accumulation rate **in *Onobrychis viciifolia* compared to *Festuca arundinacea* (%)**					
	Cu	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Control	32.1	17.1	61.3	27.5	-	39.1
Fly ash + volcanic tuff	28.6	-	21.2	36.7	-	5.7
Fly ash + modified volcanic tuff	55.3	-	35.5	-	-	15.2
Fly ash + biosolids + volcanic tuff	19.4	7.5	41.7	40.5	-	49.2
Fly ash + biosolids + modified volcanic tuff	18.2	-	52.8	-	67.7	31.9

4. Conclusions

The legume species accumulated higher concentrations of metals than the grass species. *Onobrychis viciifolia* was more affected by the environmental conditions and by weather and had half of the abundance of *Festuca arundinacea*.

The legume plants accumulated large amounts of metals that will cause damage to the plant and gradual disappearance of the sown area. *Festuca arundinacea* accumulated smaller amounts of metals and plants appeared more tolerant to the environment; they withstood a period of several months, even on the layer of ash unfertilized and amended with modified tuff which reduces the access of metals into plant tissues.

Interdependence of soil factors with plant specificities may be improved with a proper treatment allowing plants to adapt and withstand the specific biotope conditions on ash dump. Plants then may participate in the enrichment with humus of the topsoil of ash and may have less impact on the installed ecosystems.

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