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Research Article

Bioremediation of areas devastated by industrial waste

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ABSTRACT

The object of research in this paper are industrial landfills, i.e. finding the best way to change their purpose and turning them into useful areas. As a method, bioremediation was chosen, i.e. planting of certain biological species in order to change the composition of the soil. Paulownia elongata was selected from the biological species. For the purpose of the research, the location was selected and the plant species planted in the appropriate industrial substrate (ash created by burning fossil fuels) and its change in chemical composition and morphology during the two years of vegetation was monitored.

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INTRODUCTION

It is a common occurrence, whether due to poor planning or rapid growth of industrial capacities, the emergence of industrial landfills at sites near major cities.

In the beginning, this was not a big problem, when some alternative solutions were planned, but over time, as cities developed and with increasing needs for urbanization, the problem became bigger. There were generally no integrated solutions to the problems of industrial landfills near cities, there were only some partial solutions [1–3].

In this paper, an attempt was made to give a completely new approach, and that is that the material in landfills is not transferred to other locations, but that it is used as a "substrate" for planting biological material. The task of biomaterials/trees, in addition to improving the appearance of surfaces, is also bioremediation, i.e. time cleaning of the soil from heavy metals. The ultimate goal is to use the same biomaterial after 7–10 years as an alternative fuel in the cement industry and incorporate it together with the absorbed metals into the building material [4, 5].

In previous analyses, a number of professional and scientific papers have been published that have treated the problem of the use of alternative materials in the cement industry, i.e. the possibility of reducing gas emissions [6–8]. One of the studies analyzed the possibility of re-engineering the plant itself in order to adapt to modern trends of "green economy" [9]. Part of the research, as an object of observa-

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Figure 1. ICP-OES instrument.

Figure 2. Planting material, seedlings of Paulownia elongata.

Figure 3. Landfill and sample of the "Black Sea", location Lukavac Bosnia and Herzegovina.

Figure 4. Paulownia elongate seedlings on the substrate of industrial sediment "Black Sea".

tion, had the possibility of waste separation and application as a raw material component in cement production [10]. It is especially worth mentioning the applicable research in the formation of bio-parks on devastated areas in order to improve the environment in urban areas [11–13].

MATERIALS AND METHODS

The paper presents the experimental results of the analysis of the "Black Sea" or ash resulting from the combustion of fossil fuel coal and the plant Paulownia elongata, which was planted in the mentioned substrate/industrial sludge. Sample analysis and preparation was performed according to ISO 11466 [14]. Paulownia soil and sample analyses were performed on an Optima 2100 DV based on optical emission spectrometry (OES).

There are a number of published papers that have the treatment of industrial waste as their object of research, i.e. its final purpose [15]. The goal of modern industry is to return as much waste material as possible to the process or recycle it [16]. Those materials that failed to be recycled or separated mostly end up in industrial landfills. One of the methods of treatment of industrial waste located in landfills is the possibility of planting biomaterials or bioremediation. The plant Paulownia elongata was used for experimental research. The plant is characterized by exceptional properties, and it is especially worth noting the absorption of CO_2 from the atmosphere and the ability of bioremediation of contaminated soil [17, 18].

Paulownia is a tree adaptable to the terrain, it is weather resistant, it recovers and regenerates the soil, very decorative and beautiful, environmentally non-aggressive planting, as well as it is an oxygen manufacture and a weapon against global warming, it is a producer of cellulose, fodder and excellent nectariferous plant, while Paulownia is growing rapidly and gaining weight.

RESULTS AND DISCUSSION

Seedlings of Paulownia elongata were prepared in exactly the same conditions for planting in the spring months. Figure 2 shows the preparation of planting material.

The material that will play the role of compost in this case is the sediment of the "Black Sea" which was collected from the industrial sludge and shown in Figure 3.

After planting, without any additional nutrients (water, fertilizer, etc.), the plant had a period of adaptation and growth. In fact, planting conditions at an industrial landfill were simulated. The morphological characteristics of the tree, height, tree circumference, number of leaves, leaf area, etc. were measured monthly. Figure 4 shows Paulownia elongate seedlings after 4 months of growth.

Table 1. Analysis of industrial sediment "Black Sea" factory Sisacam Soda Lukavac

Element	mg/kg	Element	mg/kg
Ca	43173,33	Ti	448,00
Fe	28393,33	Na	442,00
Mg	7073,33	Mn	333,20
Al	20373,33	Sr	230,00
K	1704,00	Ni	177,23
Co	15,86	Ba	161,46
Cr	92,36	Cu	35,66
V	36,03	Zn	21,16

After the end of vegetation, for a period of 9 months, the period March-November for analysis, samples were taken from one tree and leaf seedling and prepared for analysis according to ISO 11466 on optical emission spectrometry (OES). Other seedlings were left for observation for another year of growth.

The results of the analysis of the "Black sea" sediment of the Sisacam Soda Lukavac factory are shown in Table 1.

Based on the data in Table 1, the large presence of Ca, Fe, Mg, Al, Ba, K, Mn, Ni in the industrial sediment is evident, which is a consequence of the combustion of fossil fuels, mostly coal. Data from the analysis of Paulownia elongate trees and leaves after a vegetation period of one year are given in Table 2. For comparison, columns 2 and 3 provide data from a reference sample, i.e. a Pulownia seedling that was not planted in industrial sludge.

Figure 5 and Figure 6 shows element concentrations up to 180 mg/kg and more than 500 mg/kg.

Based on the obtained results, it is evident that the plant Paulownia elongata has very good phytoremediation abilities.

From the data given in Table 2 end Figure 5, 6 it is clear that in relation to the reference sample in the samples

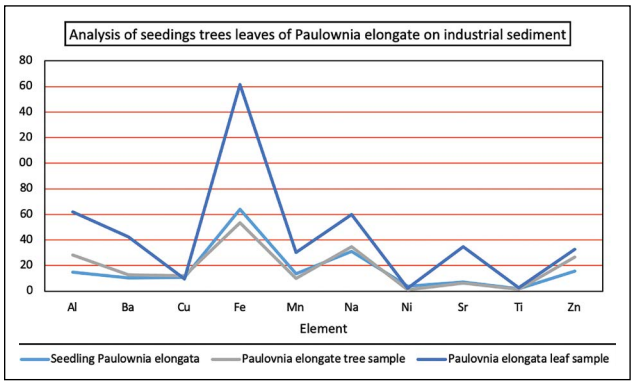

Figure 5. Analysis of seedlings, trees and leaves of Paulownia elongate on industrial sediment element concentrations up to 180 mg/kg.

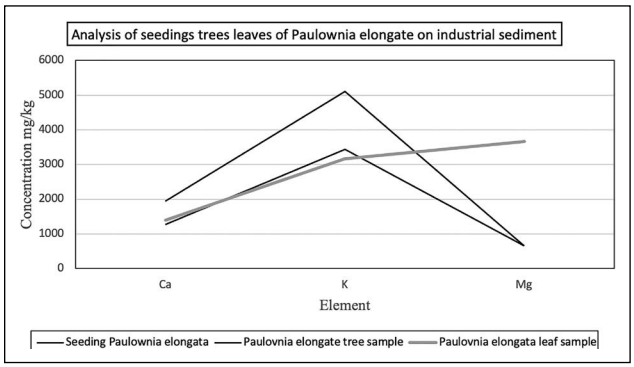

Figure 6. Analysis of seedlings, trees and leaves of Paulownia elongate on industrial sediment element concentrations more than 500 mg/kg.

of trees and leaves, there is undoubtedly a higher presence of metal originating from the substrate or industrial sediment. "Black Sea". It is especially worth noting the absorption power of Paulownia according to K, Mg, Ca, Sr, Al, Ba.

Table 2. Analysis of seedlings, trees and leaves of paulownia elongate on industrial sediment "Black Sea" sisacam soda lukavac

Element mg/kg	Seedling paulownia elongata		Paulovnia elongate tree sample		Paulovnia elongata leaf sample	
	Original sample	Ash	Original sample	Ash	Original sample	Ash
Al	14,88	51,34	28,34	55,67	62,15	97,37
Ba	10,53	11,60	12,68	15,58	42,57	47,04
Ca	1935,98	2313,49	1267,23	1621,70	1389,30	1395,31
Cu	10,76	12,51	11,92	9,97	9,44	8,96
Fe	64,24	89,76	53,48	59,53	161,33	139,04
K	5109,36	5203,48	3437,02	3524,85	3161,84	4186,02
Mg	662,50	761,11	649,77	850,97	3661,81	3728,36
Mn	13,62	16,36	10,15	11,60	30,47	29,61
Na	30,92	30,63	34,87	22,92	60,13	21,31
Ni	3,89	1,56	1,23	1,25	2,26	1,29
Sr	7,04	8,17	6,26	8,87	34,95	38,91
Ti	1,77	2,77	1,63	2,64	2,64	2,89
Zn	15,57	17,83	26,61	27,98	32,68	31,54

Based on the intensity of bioremediation in the first year, it can be assumed that the plant after 7–10 years will collect a significant amount of metals present in the soil and thus achieve one of its tasks and that is to change the quality of soil composition.

Taking into account its energy value of some 17, 68 kJ/kg, it will certainly represent a good biofuel in the cement industry.

CONCLUSIONS

Based on the conducted research, the following conclusions can be drawn:

- After direct planting in industrial "compost" containing only industrial sediment of the "Black Sea", the Paulownia elongata plant showed excellent adaptation and all seedlings of the plant developed quite normally.
- Growth in this type of compost, without additional fertilization and watering has shown that the plant is fully adaptable to different weather conditions and adaptable to industrial landfills that are usually outside urban areas and where there is no possibility of constant irrigation.
- Growing in a time interval of 9 months in compost from industrial waste, the plant Paulownia elongata showed good phytoremediation properties, especially in the absorption of Ca, K, Mg and other heavy metals.
- Similar experiments need to be done in natural conditions and with other industrial wastes for comparison. The fact is that after a year of research, good results are obtained, and it is known that only after the seventh year, the tree is cut down to a height of about 18 meters and a more intensive process of metal absorption from the soil is expected.
- In the future planting on industrial surface is already planned. Urban solutions for the conversion of space have been made. In this way, the space intended for industry becomes part of the urban space of the city.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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