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THE POSSIBILITY OF USING MACROPHYTES IN LAKE PALIĆ SEDIMENT REMEDIATION

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Abstract - Lake Palić is a typical, shallow Pannonian plain lake, with thick sediment layers and high content of phosphorus and nitrogen. The thick layers are the result of accelerated eutrophication, and cause biodiversity loss and disruption of the ecosystem. Numerous methods can be used to overcome the problem of accelerated eutrophication, (sediment removal, phosphorus inactivation etc.). However, these methods have many deficiencies. Lately, using macrophytes as a way to resolve this problem is becoming more and more popular. The aim of this work was to examine the germination possibilities of white mustard (*Sinapis alba* L.), alfalfa *(Medicago sativa* L.), oats *(Avena sativa* L.) and lettuce *(Lactuca sativa* L.) on Lake Palić's sediment, as a prescreening test for their suitability for further phytoremediation. The results show that plant species can germinate and grow in early stages in such substrates, so they can be recommended for sediment phytoremediation.

Key words: Eutrophication, sediment, mustard, alfalfa, oats, lettuce

INTRODUCTION

Lake Palić is a shallow lake created million years ago in the wind-opened gaps between the dunes of the Pannonian plain. It lies near the town of Palić, 8 km from Subotica. Situated in an urban environment, Lake Palić is intensively used as a recipient of Subotica's treated municipal wastewater. Without recharging it with water of acceptable quality, the lake is faced with a problem of rapid eutrophication. Accelerated eutrophication is partly the result of numerous diffuse and point sources of nutrients, but it is also greatly influenced by an increased use of mineral fertilizers on the surrounding agricultural areas (Raičević et al., 2011). Because of intensive eutrophication, thick layers of sediment are being formed, enriched with nitrogen and phosphorus. Lake sediment acts as an accumulation pool of nutrients (Qin et al., 2006) and primarily as a source of phosphorus for the water column and wildlife (Baudo et al., 1990).

The Lake covers 565 ha and has a volume of 10 million m^3. The estimated volume of the sediment is 1,900,160 m^3, with a thickness varying from 0.3 to 1.5 m (Božić et al., 2011). The Lake is divided into 4 sectors. The fourth sector is designed for recreation. The water quality of sector IV does not fulfill the standards recommended for recreational purposes. The first measures that should be implemented in order to recover the recreational potential of sector IV are directed at halting the increasing eutrophication, and solving the problem of the sediment.

There are many techniques for improving eutrophic lake conditions involving a systematic approach, starting with the control of external nutrient inputs and internal nutrient release (Madgwick, 1999). Decreasing the quantity of nutrients in lakes is a basic measure in the fight against eutrophication. However, it is very difficult to improve lake conditions in a short period of time, even if all external pollutants are under control. The reason for this is

Table 1. Physical and chemical characteristics of the sediment in sector IV (Božić et al., 2011).

parameter	unit	value	parameter	unit	value
thickness	m	0.00-0.30	As	mg/kg	38.6
moisture	%	17	Cu	mg/kg	18.9
organic matter	%	16	Zn	mg/kg	41.2
mineral matter	%	84	Cr	mg/kg	26.8
sand	%	70.5	Cd	mg/kg	0.4
physical clay	%	29.5	Ni	mg/kg	23.1
pH value	-	8.42	Pb	mg/kg	15.6
Total P	mg/kg DM	2.885	Hg	mg/kg	<0.2
Total N	mg/kg DM	4.3			
TOC	mg/kg DM	39			

the enormous amount of phosphorus accumulated in lake sediment (Søndergaard, 2007) which is released into the water under certain environmental conditions (Ribeiro et al., 2008). Using macrophytes to control and remove nutrients, primarily soluble phosphorus, is becoming a more and more attractive strategy for resolving the consequences of intensive eutrophication (Sharma et al., 2007), and the application of plants in soil, sediment and water remediation represents a low-cost method compared to conventional methods of remediation of contaminated sites (Susarla et al., 2002). Phytoremediation involves many processes related to plants, such as biotransformation, phytoaccumulation, phytoextraction, phytovolatization and rhyzodegradation to increase the microbial activity in the rhizosphere (Mirgain et al., 1993; Susarla et al., 2002; Walton and Anderson, 1990).

The aim of this research was to investigate the potential for using ecoremediation techniques in the remediation of sediment enriched with a high quantity of phosphorus and nitrogen. The possibility of germination and early growth of chosen plant species on the sediment of sector IV of Palić Lake was investigated.

MATERIAL AND METHODS

The study was conducted at the Microbiological Laboratory of the Department for Microbial Ecology, Faculty of Agriculture, University of Belgrade.

Sector IV sediment from coastal parts of the Lake was used for this investigation. The basic physical and chemical characteristics of sector IV are shown in Table 1.

Microbiological properties of the sediment

The number of microbial populations was determined by the dilution method. The total number of bacteria was determined on 0.1xTriptonite soy agar (TSA). Fecal coliform bacteria were determined on Petri film (3M Microbiology Products, USA) incubated at 44°C, fungi on rose bengal streptomycin agar (Peper et al., 1995) and actinomycetes on starch-ammonia agar. Microbial properties were examined at the beginning and after the third repetition of seed germination in the sediment. The microbial population was expressed as CFU x g^{-1}.

Seed germination on the sediment

During the examination period, the germination of mustard (*Sinapis alba* L.), alfalfa *(Medicago sativa* L.), oats *(Avena sativa* L.) and lettuce *(Lactuca sativa* L.*)* were tested. The seeds were sterilized with 3% H_2O_2 for 10 min and then washed with sterile, deionized water. The germination and growth of each plant seed was observed over a 10-day examination period. The experiment was performed in triplicate. After the ex-

Table 2. Microbiological characteristics of the sediment in sector IV (CFU x g^{-1}) before and after plant growth.

		Total bacteria	Fungi	Actinomycetes	Coliform bacteria	Fecal bacteria
Before		$1.77x10^7$	$4.19x10^4$	$6.05x10^5$	0	0
After	Lettuce	$3.30x10^7$	$6.93x10^4$	$1.50x10^6$	0	0
	Alfalfa	$7.86x10^7$	$5.85x10^4$	$3.46x10^5$	0	0
	Mustard	$3.88x10^7$	$2.48x10^4$	$4.92x10^5$	0	0
	Oats	$8.49x10^7$	$2.38x10^4$	$1.68x10^6$	0	0
	Average	$5.88x10^7$	$4.41x10^4$	$1.01x10^6$	0	0

amination period, the plants were removed and the percentage of germination and growth parameters (total length of seedlings, fresh and dry weight biomass, germination index and vigor index) were recorded. Germination of examined plant species was determined in comparison to the control (wet filter paper).

The germination index was calculated according to Abdul-Baki and Anderson (1973):

$$GI = \frac{n}{d}$$

where n is the number of emerged seeds in day d and d is the day after planting.

The vigor index was calculated as follows (Rahnama and Tavakkol-Afshari, 2007):

$$VI = \frac{Ls \times Pg}{100}$$

where VI is the vigor index, Ls is the mean of seedling length (mm) and Pg is the germination percentage.

RESULTS AND DISCUSSION

Eutrophication is a widespread problem all over the world. One of its consequences is the formation of thick layers of sediment that significantly change the conditions of life in a lake and violate the natural equilibrium. In many lakes during the 20th century the input of N and P from urban communities has led making clear water murky and the replacement of submersed macrophytes with phytoplankton (Jeppesen et al., 2005; Körner, 2002). The sector IV sediment examined in this paper is loaded with a high content of N and P (Table 1), provided that the availability of phosphorus is considered the most important factor for the overall state of the environment of Lake (Søndergaard, M., 2007).

The composition of sector IV sediment of Lake Palić is mostly mineral (it consisted of 84% of mineral matter), with a 16% share of organic matter (Table 1). The features of the sediment that are important for its remediation, are a high pH value, overabundance with nitrogen and phosphorus and a content of heavy metals below Dutch sediment quality guidelines (Božić et al., 2011).

Microbiological characteristics of the sediment

Based on microbiological results, it is clear that the dominant microbial group was bacteria, but a significant presence of actinomycetes was recorded as well. It is important to emphasize that there was no fecal bacteria in the samples.

The number of microbial populations after plant growth was greater compared to the initial sample (Fig. 1). The largest increase in fungal population was found in the sediment where lettuce was grown, and the greatest increase of total bacteria and actinomycetes was found in the sediment where oats

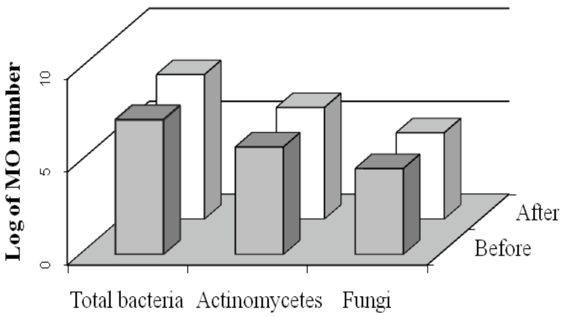

Fig. 1. Comparison of the number of microorganisms before and after plant growth.

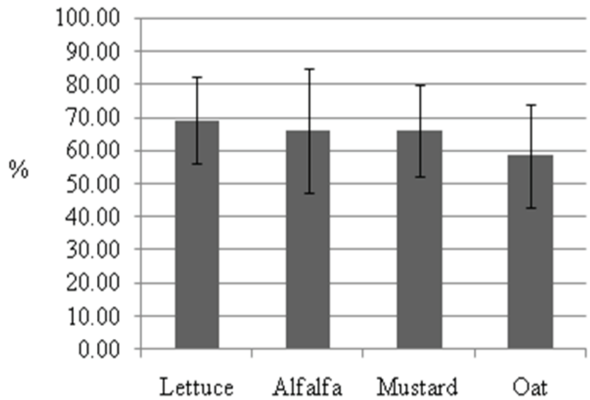

Fig. 2. The percentage of germination per species .

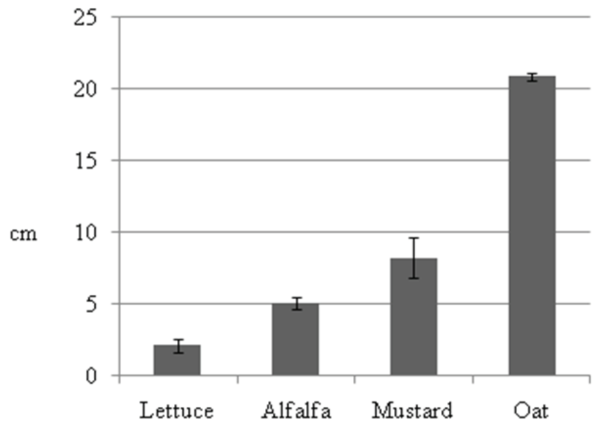

Fig. 3. The average length of seedlings per species.

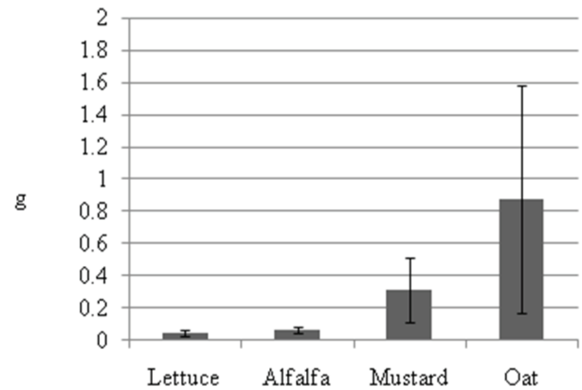

Fig. 4. The average dry biomass per species

were grown. Similar results were obtained by Lin and Mendelssohn (2009), which relate the high root biomass and root exudates of *J. roemeranus* with the number of microorganisms and their activity.

With this in mind, the obtained increase in the number of microbial populations in the sediment of secgtor IV of Lake Palić after plant growth (Table 2) may indicate the importance of using plants in its remediation, and microbial interactions to stimulate plant growth (Berg, 2009) by bacterial absolving of nutrients from different compounds (Unno et al., 2005) can be expected.

Germination, length of seedlings and plant dry biomass

The choice of plants is of crucial importance for phytoremediation efficiency on polluted sediments (Bert et al., 2009). Phytoremediation could be a more economical option, particularly suitable for *in situ* remediation of large sites, and it is environmentally friendly. Phytoremediation is rarely included in the management scheme of contaminated sediment and accepted as a viable option. Therefore, it is necessary to focus research not only to the choice of aquatic but to already significant agricultural plant species.

The germination of the chosen plant species was from 69.14% to 58.33% in comparison to the control (Fig. 2). This experiment was repeated three times, and a deviation from 55.56-81.48 % was observed with lettuce, 46.3-83.33% with alfalfa, 55.00-81.67% with mustard and 41.6-72.22% with oats.

Table 3. The germination and vigor index of plants grown at the sediment.

	lettuce		alfalfa		mustard		oats	
	cont.	sediment	cont.	sediment	cont.	sediment	cont.	sediment
Germ. index	1.8	1.25	1.8	1.18	2	1.32	1.4	0.76
Vigor index	50	27.6	20.7	13	64	48	88	57.4

The highest germination in the sediment was observed in the lettuce (Fig. 2) even though this plant species is known to be extremely sensitive. The high loading of sediment with phosphorus indicates the necessity of choosing plants with a high potential for the accumulation of this element (Sharma et al., 2007), but which can grow in these conditions.

Ten days after sowing, the average length of the seedlings was recorded (Fig. 3), and the lettuce ranged from 1.82-2.25 cm, alfalfa from 4.17-5.04 cm, mustard 4.47-8.88 cm and oats 13.93-18.90 cm.

Only specific plant species can produce a sufficiently high biomass in sediments polluted by heavy metals (Vandecasteele et al., 2008), PAHs (King et al., 2006), etc. In addition, the mechanical characteristics of a substrate can affect plant growth and biomass production, and in such conditions, only specific plant species can grow.

The biomass in the dry state recorded ten days after sowing lettuce was between 0.0251-0.0594 g, alfalfa 0.0532-0.0860 g, mustard 0.0925-0.4868 g, and oats 0.1690-1.5830 g (Fig. 4).

The phytotoxicity of the sediment was investigated by measuring the germination using the germination and vigor index, and these parameters can be used for the evaluation of the detoxification speed and rate during the bioremediation process (Aparna et al., 2010).

The recorded values of the germination and vigor indices of the tested species grown in the sediment were lower compared with the control (Table 3).

The germination index of all tested plant species grown in the sediment was lower and this decrease was almost 50%. In addition, the values of the vigor index were lower than the control values. During plant growth in the sediment, the necessary nutrients for development are used, consequently reducing their content. Significant amounts of nutrients are reduced by removing macrophytes from the sediment. This is also a way to avoid the secondary pollution that emerges from plant material, which shows this method to be a good solution to the eutrophication problem (Das and Tanaka, 2007; Graneli and Solander, 1988).

Despite the lower values of measured parameters in relation to the control and the unfavorable mechanical properties of sediments, these species can be used in remediation technologies. The growth of these species in the initial stages has great importance for further growth of these plants (Sadeghi et al., 2011), which provides a good basis for the use of these plants in remediation technologies.

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