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METHODS OF PHYTOREMEDIATION OF SOIL

Abstract

Land, as the basic resource for food production, is of paramount importance to the human population. The process of phytoremediation is what allows us the capability to preserve soil in case of contamination. This paper describes five techniques of soil purification. The process encompasses a number of different methods that can lead to the decomposition of contaminants (1) within the above-ground plant tissue, as is the case with the process of phytodegradation, or (2) in the root zone of plants, which is characteristic of the process of rhizodegradation, then, (3) it can bring about acquisition or absorption, which is characteristic of the processes of phytoextraction and phytovolatilisation, and, finally, (4) it can immobilise contaminants in the root zone, which occurs in the process of phytostabilisation.

Keywords: *phytoremediation, soil, contamination.*

INTRODUCTION

Intensive farming is increasingly being profiled by the use of synthetic agents such as fertilisers, pesticides and others (Ugrenović et al., 2012). Improper use of these agrochemicals leads to an increase in their content in the soil, frequently exceeding the prescribed permissible limits. This leads to a reduction in soil fertility and the destruction of biodiversity in an irreparable way. Soil biodiversity is the central part of our natural systems. But, it is also under ever growing pressure from human activities (Filipović and Ugrenović, 2012). One of the methods to purify soil and facilitate further improvement of soil biodiversity is the method of phytoremediation. The process represents a series of techniques that use the ability of plants, obtained naturally or through the means of genetic engineering, to perform the decontamination of the environment (Flathman and Lanza, 1998). Phytoremediation is a clean, simple, economical and ecologically sustainable method (Wei et al., 2004); it is a green technology whose byproducts can have many positive impacts (Truong, 1999). By this method, we can carry out the decontamination of the soils contaminated with inorganic pollutants such as toluene, benzene, Polycyclic aromatic hydrocarbons (PAHs), ethylbenzene and many chlorinated solvents (US Environmental Protection Agency – U.S.EPA, 2000). The procedure can be performed *in situ*, i.e. exactly at the place of pollution, or *ex situ*. The ex situ method requires excavation, relocation and performing detoxification at another location, followed by the return of the treated soil to its original location. The difference between these methods is that the in situ one is considerably cheaper, but it takes a significantly longer period of time for the process to be carried out.

The success of phytoremediation depends on the potential of a plant to acquire and accumulate pollutants in its biomass, then, on the availability of contaminants to the root system of the plant, on the overall level of soil contamination and on the type of contaminant. It is necessary that phytoremediation plants be characterised by a high capacity for acquisition, translocation and tolerance towards a contaminant (the US Environmental Protection Agency – U.S.EPA, 2000). Large plant diversity is typical of organic agriculture, which, through various methods (multi-year crop rotations, intercropping, cover crops, insulating belts, etc.) makes possible the exercise of phytoremediation at different times and production conditions (Ugrenović and Filipović, 2012).

PHYTOEXTRACTION

Phytoextraction is a method that exploits the potential of higher vascular plants to perform the acquisition of contaminants from the soil. The process is performed by those plants that are able to acquire a contaminant through the root system, and pass it through the system of transpiration to the aerial parts (stem and leaves). The contaminants are displaced by cutting the above-ground biomass of plants once a certain stage of development has been reached. Phytoextraction is a technique that is most commonly used on soils contaminated with heavy metals and radionuclides. Apart from soil purification, phytoextraction is used for the remediation of sediments and sludge, and, to a lesser extent, for the treatment of contaminated water. According to the research so far (G.M. Pierzynski, 1994), the metals that are subject to the process of phytoextraction are: metals (Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn), then, metalloids (As, Se) and radionuclides (90Sr, 137Cs, 239Pu, 238U, 234U).

Plants that expressly perform phytoextraction are called *hyperaccumulators*. Hyperaccumulators are able to absorb 50–100 times greater concentrations of heavy metals in relation to their own biomass, and, in relation to the plants which do not acquire heavy metals (Salt et al., 1995). To date, over 500 hyperaccumulative plant species in over 45 plant families have been discovered (Sarma, 2011). Hyperaccumulators were found in the following plant families: *Brassicaceae*, *Euphorbiaceae*, *Asteraceae*, *Lamiaceae* and *Scrophulariaceae* (U.S.EPA, 2000). According to the research (Kumar, 1995), the plant species *Brassica Junaceae* (Indian mustard), with great biomass, is able to accumulate Pb, Cr, Cd, Cu, Ni, Zn, Sr, B, and Se. Probably the most successful plant hiperaccumulator of metals from the family *Brassicaceae* is *Thlaspi caerulescens*. While the majority of plants display the symptoms of toxicity during the accumulation of zinc (Zn) at the concentration of 100 ppm, this plant is capable of accumulating 26000 ppm without any consequences (Brown et al., 1995). Hyperaccumulators are plants that are widely distributed in nature, and are most commonly found only in certain eco-habitats. The drawback of hyperaccumulators in the process of phytoextraction is that, in most cases, they are with a small growth and with little biomass. In addition to these shortcomings, hyperaccumulators also seek special conditions for their growth and development, and are not adaptable to a wide range of habitats. Furthermore, hyperaccumulators do not acquire a large amount of metals from the soil itself, as compared with the total amount of metals contained in the soil, and given the fact that there are no efficient hyperaccumulators for certain pollutants. Because of these reasons, it is necessary to carry out further research on the selection, genetic breeding and utilisation of plants with significantly greater biomass, more intensive growth and a more rapid development. Plants with these characteristics would, in relation to their biomass, absorb a lower concentration of pollutants, but would also acquire a higher total amount of metals from the soil. The research with large biomass plants was done with four types of sorghum, specifically, with broomcorn, sweet sorghum, Sudan grass and grain sorghum (Angelova et al., 2011). The soil that was examined was contaminated with lead, copper, zinc and cadmium. The results showed that Sudan grass and broomcorn have high potential for phytoextraction, because they acquired a considerably larger amount of metal in comparison with grain sorghum and sweet sorghum. In addition to sorghum, corn was another major biomass plant that showed good results in the phytoextraction of lead and cadmium (Mojira, 2011). Based on examinations (Oh et al., 2013), sunflower showed greater accumulation of lead, copper and cadmium in relation to corn, but also, a lower tolerance to metals absorbed.

PHYTOSTABILISATION

Phytostabilisation is a method by which a plant performs the reduction in mobility or the immobilization of a contaminant that is situated in the area of the root system of the plant. The plant excretes enzymes, which results in the change of chemical, biological and physical conditions in the soil, and leads to the retention of the contaminant in the rhizosphere zone. That is the reason why the contaminant remains immobilised. Its movement through the soil and the ecosystem, which can be caused by any kind of erosion or leaching in the soil, is prevented this way. The process takes place through the means of microbiological or chemical mechanisms of the root zone itself, by which, changes occur to the chemism of the soil and/or the contaminating substance. What results is the change in the soil pH value, as an effect of the separation of root exudates. A pollutant can be reduced through the process of absorption and accumulation by roots, then, through the reduction of the valence of metals, lead, chromium and mercury in the soil (U.S.EPA, 1997). Beside the possibility of immobilisation of inorganic materials, primarily metals, according to research (Harms and Langebartels, 1986), there is the potential for the exercise of phytostabilisation of organic contaminants by associating an organic contaminant or its byproducts with the lignin within the plant tissue in its above-ground parts. This procedure is called *phytolignification*. For the process of phytostabilisation, the plants are needed that can grow in contaminated soil, with the roots that grow in the area of contamination and can perform changes in the biological, chemical and physiological conditions in the soil. The advantage of this method is that it is not necessary to do the dislocation of neither the soil nor the biomass from the site of contamination. Thus, the technology is not expensive. The primary disadvantage of this method of remediation is that a contaminant remains present in the soil at a given location, linked to parts of plant vegetation. There is also a risk, because it may come to an increase in the solubility of heavy metals and their subsequent washing towards the deeper layers outside the reach of the root system (Salt et al., 1995). The plant species that have shown great potential in the process of phytomobilisation are Indian mustard and hybrid *Populus* species (Pivetz, 2001).

PHYTODEGRADATION

Phytodegradation is a method of soil remediation, in which a plant performs the acquisition of contaminants from the soil, and then, through the biochemical processes performed within the plant tissue, the decomposition of contaminants is performed. This method is highly successful in the displacement of organic contaminants from the soil. In order to reach the process of phytodegradation, it is necessary that the plant adopt organic compounds that are supposed to carry out the degradation. Whether the plant will acquire a contaminant depends on the type of contamination, its concentration, plant species and soil conditions (Prasad, 2011). One study showed that more than 70 chemicals that comprised various components were acquired by 88 plants and tree species (Paterson et al., 1990). The acquisition of an organic contaminant depends on its hydrophobicity, solubility and polarity. Very soluble compounds will not be acquired and translocated into the plant (Schnoor et al., 1995). Also, phytodegradation takes place in the zone of the root system of the plant, wherein microbiological degradation of organic contaminants takes place, which occurs with the participation of the plant, that is, in a part of the rhizosphere. The plant produces enzymes which affect metabolic processes, and it comes to the decomposition of contaminants. Additionally, as a result of the respiration of microbiological population, there comes to a reduction in oxygen content, that is, to the formation of reducing conditions in the surrounding environment, which contributes to more rapid decomposition of a contaminant. In either case, the degradation of organic molecules represents an enzymatic reaction. These enzymes include: dehalogenase, nitroreductase, peroxidase, lactase and nitralase (Schnoor et al., 1995). Many of the plant enzymes are capable of metabolising several chemicals completely to carbon dioxide and water (Prasad, 2011). The enzymes are associated with the processes of transformation of organic contaminants such as: chlorine compounds, waste ammunition, phenols and herbicide residues (U.S.EPA, 2000).

Good results in the process of phytodegradation can be achieved on soils that do not have active microflora, and are thus unable to carry out the decomposition of contaminants. The deficiency lies in the possibility of the formation of toxic compounds and metabolic intermediates which may have the potential of adverse effects on the environment.

PHYTOVOLITISATION

Phytovolitisation is the process by which plant performs the absorption of contaminants from the soil, and transmits them through the transpiration system to a spot within the plant tissue where a chemical change is performed through metabolic processes. A harmful compound is thus converted into a less harmful form. After the change, the process of transpiration is carried out, and the plant releases the compounds into the atmosphere in a less toxic or non-toxic form. Current climatic conditions that the plant is exposed to in the course of phytovolitisation significantly affect the process. Temerature, wind, precipitation, insolation and air pressure can affect the success and the amount of a transpired contaminant. A disadvantage of this method is that, during the process, potentially harmful compounds can be assembled, which can have carcinogenic effects upon the emission. Another disadvantage is the possibility of the accumulation of harmful metabolites and intermediates in the plant tissues and fruits, in which case, they can enter the food chain.

Most of the research so far has dealt with the possibility of the acquisition of selenium, mercury and arsenic from the soil, their changes and the release into the atmosphere in a less toxic form. According to the research (Sakakibara et al., 2010), excellent results in the phytovolitisation of arsenic were achieved by the plant *Pteris vittata*, i.e., Chinese fern. An experiment showed that the plant had adopted about 90 percent of arsenic from the soil, and released it into the atmosphere. Excellent results in the phytovolitisation of selenium were achieved by *Brassica junaceae*, i.e., Indian mustard (Banuelos et al., 1997b).

RIZODEGRADATION

Rhizodegradation is the process by which soil microorganisms carry out the decomposition of organic contaminant in the rhizosphere. Contaminants that are exposed to the process of decomposition in the soil are organic contaminants of high hydrophobicity, and, as such, cannot be acquired by a plant. Through the root, a plant indirectly stimulates the process of rhizodegradation. The root excretes exudates such as polysaccharides, amino acids, organic fatty acids, growth factors, sterol, nucleotides, flavanones, enzymes, and other compounds (Pievtz, 2001). The activity of root exudates contributes to higher growth and the reproduction of microorganisms. Thus, microorganisms rather significantly perform the decomposition of organic matter. Also, the effect of exudates can cause changes in the pH of the soil, which can result in a change in the transport of contaminants (Pivetz, 2001). Apart from producing exudates, root has a positive effect on the process rhizodegradation, because it increases aeration, water content in the soil, nutrient content, the transport of nutrients, soil structure, temperature. Given that the process of the decomposition of organic matter takes place in the soil, it is not necessary to carry out the cutting of aboveground residues, because the plant does not acquire contaminants. Therefore, there is no transfer of contaminants through a plant to the food chain. The above-mentioned reasons bring us to the conclusion that rhizodegration stands for an inexpensive technology. The limiting factor in the process of rhizodegradation is the depth of the root of a plant, particularly, when it comes to plants with shallow root systems. Also, soil with severe compaction may limit deeper development of roots. A problem may occur if root exudates begin to stimulate the growth of microorganisms that do not perform the decomposition of organic matter (Pivetz, 2001), or if a plant begins to use organic contaminants as a source of organic matter instead of carbon, which would reduce the amount of a decomposed contaminant (Molina, 1995).

CONCLUSION

Phytoremediation represents a natural technology that exploits the ability of plants to perform soil remediation. It contributes to environmental protection. The technology is inexpensive and relatively easy to carry out. Depending on the applied method, remediation is performed of either organic or inorganic contaminants.

A lack of technology is that it is a time-consuming process compared with other methods of contamination displacement from the environment. It is applicable only to shallow soils. Phytoremediation is effective only with moderately hydrophobic compounds.

A threat to the health of humans and animals may occur if plants used in some of the methods of phytoremediation enter the food chain.

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NAČINI FITOREMEDIJACIJE ZEMLJIŠTA

Apstrakt

Zemljište, kao osnovni resurs za proizvodnju hrane, od najvećeg je značaja za ljudsku populaciju. Proces fitoremedijacije su ono što nam daje mogućnost za očuvanje zemljišta usled zagađenja. U radu je prikazano pet tehnika prečišćavanja zemljišta. Postupak obuhvata više različitih metoda koje mogu dovesti do razgradnje zagađujuće materije (1) unutar nadzemnog tkiva biljke, što je slučaj kod procesa fitodegradacije, ili (2) u zoni korena biljke, što je karakteristično za rizodegradaciju, zatim, može da uzrokuje (3) usvajanje ili apsorpciju, što je karakteristika za fitoekstrakciju i fitovolitizaciju, i, najzad, (4) imobilizaciju zagađivača u zoni korena, što se dešava u procesu fitostabilizacije.

Ključne reči: *fitoremedijacija, zemljište, zagađenje.*

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