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TRANSFER AND BIOACCUMULATION OF HEAVY METAL IONS FROM SOIL INTO PLANTS

Abstract: *The soil is a thin surface layer of the Earth's crust formed in long-term, mutual interactions between rocks, climate and living beings. It is, conditionally, one of the renewable resources due to the long process of formation and development. The widespread contamination of soils, particularly with heavy metals, is currently one of the most serious environmental concerns. Although a small portion of heavy metals in soil is derived from natural processes, a much higher amount originates from anthropogenic sources such as industry (mining and smelting), agriculture (use of mineral fertilizers and pesticides) and transportation (automobiles and aircraft). The aim of this paper is to show the relation between the heavy metal ions content in soil and their bioaccumulation in plants. The accumulation of heavy metal ions depends on various biotic (plant species, genotype, developments stage, etc.) and abiotic factors (qualitative and quantitative characteristics of heavy metals, temperature, pH value, ion interactions, etc.). One of the abiotic factors which has recently been in focus of the research, and which is important for uptake and physiological effects of pollutants, is the interaction of ions which relate to antagonism and synergism.*

Key words: heavy metals, bioaccumulation, plants, antagonism, synergism.

INTRODUCTION

The soil is a basic natural resource which quality presents the basis of sustainable development of agriculture and forestry. Some pollutants, including heavy metals, from anthropogenic sources occur in the environment, subside in soil and have influnce on pedogenetic processes. Today, soil contamination with heavy metals is an environmental problem on a global scale, and it is becoming increasingly important as industrialization, urbanization, development of agriculture and transportation increase [1]. Heavy metals are long-term contaminants with the ability to accumulate in soil and plants [2]. All plants show a certain reaction in terms of increasing of toxic elements concentration in soil, depending upon the sensitivity of plants exposure intensity and chemical species. Some species of plants disappear from such lands, while others, on the contrary, are stimulated by these elements. In case of land which contain metals, some plant species (metalophytes) have developed tolerance towards metals ions, while others (hyperaccumulators) are characterized by the capacity to accumulate high concentration of metal ions in their tissues. The accumulation of heavy metal ions depends on various biotic and abiotic factors. One of the abiotic factors which has recently been in focus of the research, and which is important for the uptake and physiological effects of heavy metals ions, is their interaction which relate to antagonism and synergism [3,4]. The properties of plants to accumulate heavy metals were used for purification of the contaminated soil. This technology – phytoremediation - can be defined as the efficient use of plants to remove, detoxify or immobilize environmental contaminants in a growth matrix (soil, water or sediments) through the natural, biological, chemical or physical activities and processes of the plants [5,6].

HEAVY METALS

The term heavy metals applies to the group of metals and metalloids with atomic density greater than 5 g/cm^3 and atomic number greater than 20 [7,8,9]. Also, they are known as "toxic metals" [9]. Heavy metals can be divided into two groups: essential heavy metals and toxic metals. Certain heavy metals (Fe, Cu and Zn) are essential for plants and animals [10]. The availability of heavy metals in medium varies, and metals such as Cu, Zn, Fe, Mn, Mo, Ni and Co are essential micronutrients [11], whose uptake in excess to the plant requirements result in toxic effects [12,13]. They are also called "trace elements" due to their presence in trace (10 mg kg^{-1}) or in ultra trace (1 μg kg^{-1}) quantities in the environmental matrices. The essential heavy metals (Cu, Zn, Fe, Mn and Mo) play biochemical and physiological functions in plants and animals. Two major functions of essential heavy metals are: (a) Participation in redox reaction, and (b) Direct participation, being an integral part of several enzymes. On the other hand, toxic metals (Pb, Cd, Hg and As) have no physiological function.

Source of heavy metals contamination

The sources of heavy metals can be both natural and anthropogenic (agricultural, industrial, domestic effluent and other). The most important natural source of heavy metals is geologic parent material. Furthermore, important natural sources are volcanoes, wind dust, marine aerosols and forest fires [14]. Agriculture is one of the anthropogenic sources of contamination. Namely, inorganic and organic fertilizers are the most important sources of heavy metals in agricultural soil, since they include pesticides, irrigation waters and sewage sludge [15]. Regarding the industrial sources of heavy metals, they include mining, processing of plastics, textiles, microelectronics, wood preservation, paper processing, etc. With regard to pollution from urbanized areas, there is an increasing awareness that urban runoff presents a serious problem of heavy metal contamination [16]. Significant sources of heavy metals include refuse incineration, landfills and transportation (automobiles, aircraft etc.).

Factors influencing the uptake and transfer of heavy metals ions

The uptake of heavy metal ions depends on various biotic (plant species, genotype, developments stage, etc.) and abiotic factors (qualitative and quantitative characteristics of heavy metals, temperature, soil pH, ion interactions, soil aeration, Eh condition, etc.) [17]. Plants take heavy metals from soils through different reactions such as: absorption, redox reactions, ionic exchange, etc. The solubility of metals depends on minerals in soil (carbonates, oxide, hydroxide etc.), soil organic matter (humic acids, fulvic acids, polysaccharides and organic acids), as well as soil pH, redox potential and soil temperature [18]. For example, soil acidity has a major impact on ion mobility and their uptake by the plant (Figure 1).

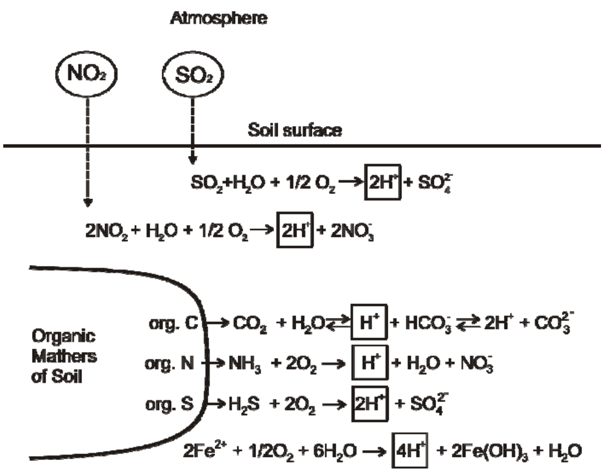

Figure 1. *Reactions that can cause the increase of soil acidity*

These facts indicate that only available ions are transferred in plants. The concentration of heavy metal ions in the environment is one of the most important factors for their uptake. Increasing ion concentration in the environment cause the increase of their content in plants; however, the increase is not linear but asymptotic. One of the abiotic factors which is important for uptake and physiological effects of heavy metals ions, as well as their concentration in environment, is a mutual interaction among various ions which relate to antagonism and synergism. Antagonism of ions is caused by the difference in their diameters, valences and electrical conductivity [19]. Antagonism of calcium and lead (Ca and Pb) is very important. If two heavy metals are found together on a nutritious medium, and if the contents of one of them exceeded the threshold of toxicity, that leads to their synergistic effects (heavy metals such as Cd and Zn).

Distribution of metals in plant

Metals distribution in plants is quite heterogenous and caused by the genetic factors, environment and toxic factors. The metals distribution in plant seems to be controlled by some mechanism and this suggests the existence of some boundaries and/or change in the metal chemical state [18]. Different plant parts contain different quantities of heavy metals, the highest ones being contained in roots and leaves, and the smallest in flower buds and fruit. The content of heavy metals of the roots may indicate the degree of these pollutants accumulation in the polluted soil, whereas the content of heavy metals on leaves may even suggest the atmosphere pollution degree.

Bioaccumulation of heavy metals in plant

The ability of the accumulation of pollutants in plants is often defined by the coefficient of bioaccumulation (ratio of concentrations of pollutants in the plant and the initial concentration in the medium). Usually, one plant species has a higher affinity to only one substance.

Our previous research of heavy metals in medicinal plants and soil, have shown that some plants such as *Sambucus nigra* L. contain higher content of cadmium in the flower, in relation to its content in the soil [20]. This has led us to determine the coefficient of bioaccumulation as an indicator of heavy metal phytoextraction (Table 1).

Table 1. *The content of heavy metals in plant species Sambucus nigra L. and soil; Coefficient of bioacumulation of heavy metals in plant species Sabucus nigra L.*

	the content of cadmium (mg/kg)	coefficient of bioaccumulation	the content of lead (mg/kg)	coefficient of bioaccumulation	the content of nickel (mg/kg)	coefficient of bioaccumulation
Locality Miljkovac	0.58	3	29.27	<1	52.69	<1
Flower *Sambucus nigra* L.	1.74		1.83		3.16	

Also, the coefficient of bioaccumulation was determined for selenium in some medicinal plants [21]. The content of selenium in soil has be presented in Table 2, while the content of selenium in plant species of the genus *Astragalus* L. and *Silene* L. and coefficient of bioaccumulation has be shown in Table 3.

Table 2. *The content of selenium in soil*

Substrate	Locality	The content of selenium (μg/kg)
Soil	Bregovi (Rudina mountain)	230
The parent substrate	Bregovi (Rudina mountain)	220
Soil	Ploče (Rudina mountain)	236

Table 3. *The content and coefficient of bioaccumulation of selenium in genus Astragalus L. and Silene L.*

Plant speces	Locality	The content of selenium (μg/kg)	Coefficient of bioaccumulation
Astragalus onobrichys L.	Ploče (Rudina mountain)	236	1
Astragalus angustifolius L.	Bregovi (Rudina mountain)	270	1.1
Astragalus vesicarius L.	Ploče (Rudina mountain)	290	1.3
Silene supina L.	Bregovi (Rudina mountain)	255	1.1

Phytoremediation

Phytoremediation is a new, inexpensive and environmentally friendly technology that is based on the use of green plants to remove pollutants from the environment. The ability of plants to accumulate metals has evolved during the long evolution of growth on soils rich in metals. Today, these plants are commonly used to remove heavy metals from soil and transform them into harmless forms. Most commonly used methods for removing heavy metals are phytoextraction, phytostabilisation, etc. The choice of method depends on: the characteristics of soil and heavy metals with the necessary knowledge of soil texture, mechanical and chemical composition, the amount of organic matter, soil pH, characteristic of heavy metals, their interactions with other elements in the soil, etc.

CONCLUSION

Heavy metal toxicity and the danger of their bioaccumulation in the food chain represent one of the major environmental and health problems of the contemporary society. In recent years, scientists have started to generate cost effective technologies which include the use of plants for cleaning polluted areas. Phytoremediation is an emerging technology, which should be considered for remediation of contaminated sites because of its cost effectiveness, aesthetic advantages and long term applicability. This technology can be defined as the efficient use of plants to remove, detoxify or immobilize environmental contaminants in a growth, through the natural, biological, chemical or physical activities and processes of the plants Also, phytoextraction is the use of live green plants in order to remove inorganic contaminants, primarily metals, from polluted soils and concentrate them into roots and easily harvestable shoots. Knowledge of the interaction of heavy metals is very important especially when soil was polluted with high concentration of heavy metals. Starting from the fact that the nickel from the soil stimulates the translocation of cadmium in the shoot, we performed phytoremediation of contaminated soil, which has been one of the issues investigated in our research.

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BIOGRAPHY

Tatjana Golubović was born in Niš, Serbia, in 1969. She received the diploma in Chemistry, and the Ph.D. degree in Chemistry from Department of Chemistry, Faculty of Science and Mathematics, University of Niš.

Her main areas of research include chemistry, environmental chemistry, soil protection and eco-toxicology. She is currently working as an associate professor at the Faculty of Occupational Safety in Niš, University of Niš.

TRANSFER I BIOAKUMULACIJA JONA TEŠKIH METALA IZ ZEMLJIŠTA U BILJKE

Tatjana Golubović, Bojka Blagojević

Rezime: *Zemljište je tanak površinski sloj Zemljine kore nastao dugotrajnim i uzajamnim delovanjem matične stene, klime i živih bića. Ubraja se u uslovno obnovljive resurse s obzirom na dugotrajne procese nastanka i razvoja. Sve rasprostranjenija kontaminacija zemljišta, posebno teškim metalima, trenutno je jedan od najozbiljnijih problema životne sredine. Manji deo teških metala u zemljištu potiče od prirodnih procesa, dok mnogo veći deo potiče iz antropogenih izvora poput industrije (rudnici i topionice), poljoprivrede (upotreba mineralnih đubriva i pesticida) i saobraćaja (automobilski i avionski). Cilj ovog rada je da ukaže na odnos između koncentracije jona teških metala u zemljištu i njihove bioakumulacije u biljkama. Akumulacija jona teških metala zavisi od mnogobrojnih biotičkih (biljna vrsta, genotip, faza razvoja itd.) i abiotičkih faktora (kvalitativne i kvantitativne karakteristike teških metala, temperature, pH zemljišnog rastvora, interakcije jona, itd.). Jedan od abiotičkih faktora koji je u poslednje vreme u fokusu istraživanja i koji je značajan zbog usvajanja i fiziološkog dejstva zagađujućih supstanci, je interakcija jona koja se ogleda u njihovom međusobnom antagonizmu i sinergizmu.*

Ključne reči: teški metali, bioakumulacija, biljke, antagonizam, sinergizam.