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INFLUENCE OF HEAVY METALS ON MICROORGANISMS

Mandić Leka[1], Đukić Dragutin[1], Semenov Aleksandar[2], Lutovac Mitar[3], Bošković Ivana[4], Bojana Trifunović[5]

1) University of Kragujevac, Faculty of Agronomy in Cacak, Cara Dušana 34, Čačak, Serbia
2) Faculty of Biology, Department of Microbiology, M. V. Lomonosov Moscow
3) Balkanski naučni centar Ruske akademije prirodnih nauka, Beograd
4) Faculty of Agriculture, University of East Sarajevo, V. Karadzića 30, 71126 Lukavica,
5) City of Cacak, city administration for urbanism, Ž. Stracimira 2, Cacak, Serbia

Abstract: *The technosphere that man created and the biosphere that he inherited are constantly in conflict. The ecological crisis that arose as a consequence of environmental pollution, concerns, above all, all of us. If we do not change our behavior, it is certain that we will not survive. Therefore, in this paper, the accumulation and other abilities of microorganisms, which should contribute to solving this great problem.*

Keywords*: biosphere, microorganisms, technosphere, pollution.*

INTRODUCTION

Of the large number of different chemical substances that reach the environment from anthropogenic sources, a special place is occupied by heavy metals. All heavy metals, and there are over 40 of them, are not equally dangerous for living organisms. According to the toxicity and ability to accumulate in various links of the food chain, only some of them are priority pollutants of the biosphere - mercury, lead, cadmium, copper, vanadium, tin, zinc, molybdenum, cobalt and nickel (Kastorii et al., 1997). mercury, lead and cadmium are the most dangerous.

During evolution, microorganisms, plants, animals and humans have adapted to the basic (natural) content of heavy metals in the soil. However, the intensive development of industry, transport, urbanism and the application of various chemical plant protection products have led to the accumulation of significant areas, even entire areas, of our planet, which negatively affects the soil, water, atmosphere and all living organisms that inhabit them (Đukić et al., 2013, 2018, 2020).

One of the most important tasks, which is related to the prevention of negative consequences of pollution of certain components of the environment, is to clarify the conditions and nature of the action of heavy metals on microorganisms (on their quantitative and qualitative composition) and enzyme activity.

Interaction between living and non-living matter in the soil

The interaction between living and non-living matter takes place most intensively in the soil, in which microorganisms play a significant role. Upon reaching the soil, heavy metals have an impact on the structure (number, composition of species) and functional state of microbial coenosis (Jemcev, Đukić, 2000; Mikanova, 2006; Đukić et al., 2007) and the activity of the enzyme catalase, urease, dehydrogenase, amylase, invertase (Balyaeva et al., 2005; Wang et al., 2007). The toxicity of heavy metals to different enzymes is not the same. In sod-underground soil, the most sensitive enzyme is catalase (Levin, 1989), while urease activity does not change under the same conditions. According to the influence on the activity of enzymes, heavy metals are classified into the following series:

$$Cd > Pb > Zn$$

Heavy metals change the total number of microorganisms. Under the influence of heavy metals, the number of oligonitrophils, ammonification and beneficial bacteria decreases. Cellulose bacteria are relatively resistant to heavy metals. It should be noted, however, that a change in the number of certain groups of microorganisms occurs only if the presence of heavy metals is twice as high as the basic (natural) level (Govedarica et.al., 1997). Heavy metals cause certain changes in the composition of microbial coenosis species (Jemcev, Đukić, 2000; Đukić et al. 2007).

Pollution of soil with heavy metals reduces the diversity of the microbial community. At the same time, species that are resistant to heavy metals appear in the micromycete community (Gavrilesca, 2004; Zafar et al., 2007). Species of the genus Bacillus are the most sensitive to heavy metal pollution, while pseudomonas, streptomycetes and many species of cellulosic microorganisms are somewhat more resistant. Therefore, it is recommended that the change in the composition of the microbial coenosis be used as a criterion for assessing the polluting effect of heavy metals. The number of species of microorganisms decreases in soil contaminated with heavy metals, while the absolute dominance of Penicillium purpurogenum, which exhibits a strong phytotoxic property, is emerging among micromycetes. When soil is polluted with heavy metals, the share of typical soil yeasts decreases sharply. Sechromogenic (pigmented) microorganisms are characterized by increased tolerance in relation to heavy metals.

At low concentrations of heavy metals, there is a certain stimulation of the development of the initiated community of microorganisms, followed by their partial inhibition and finally, complete suppression. Soil microorganisms are differently resistant to heavy metals and are in constant interaction with each other and in interaction with the soil. Therefore, the reaction of microbial coenosis to heavy metals depends on their interaction with the soil, the action on microorganisms and the competitive interaction between microorganisms. In order to assess the degree of influence of heavy metals on the microbial coenosis of the soil, four zones of resistance are singled out (Guzev, Levin, 1991).

The first zone of stability (adaptive zone), which is characterized by the lowest level of load, is the zone of homeostasis. This zone includes the range of cadmium concentration of 0-7 mg /Kg of soil, in which only the total biomass of microorganisms changes while the composition and organization of the community do not change. According to the size of the homeostasis zone, soils can be classified into a certain series. Chernozems are characterized by maximum stability, and podzolic soils with minimal stability.

The second zone of stability, which is characterized by a medium level of load, is the stress zone of microbial soil coenosis. The concentration of agents in that zone causes a redistribution of populations of microorganisms according to the degree of dominance. With significant changes in the organization of microbial coenosis, its composition does not change. Toxinogenic microorganisms mostly develop in that zone. They inhibit the germination of plant seeds, seedling development, etc. (Kastori, Petrović, 1993). At the same time, the biomass of these microorganisms is not used by terrestrial invertebrates. There is a close relationship between the degree of microbial toxicity of cultivated crops. The occurrence of toxicosis is considered to be negative and is assessed as a polluting effect of heavy metals on the soil (Verešbaranji,et al., 1993).

The third zone of stability of microbial coenosis is characterized by a high level of load and is manifested at high doses of heavy metals - zones of resistance. In this zone, the diversity of microorganism species decreases sharply and resistant populations of microorganisms develop predominantly. In this zone, heavy metals have a direct toxic effect on soil microorganisms, causing the death of most of them.

The fourth zone of stability, which is characterized by the highest level of load, which leads to the complete elimination of the growth and development of microorganisms in the soil, is called the zone of repression. Complete suppression of the activity of soil microorganisms is a diagnostic property of its strong (catastrophic) heavy metal pollution.

Therefore, the size of the homeostasis zone should be accepted as an objective criterion on the basis of which the effect of heavy metals on the

microbial coenosis of different soil types should be assessed and the potential stability (resistance) of microorganisms to pollution should be determined .
The accumulation of heavy metals in the cytoplasm of microorganisms depends on the seasonal variations of their biomass and on the content of the respective element in the soil. In biogeochemical areas with a high content of heavy metals, the microbial community of soil accumulates 3-150 times more metals than the microbial community of soil from areas with their basic (natural) content. Heavy metal pollution causes a decrease in the nitrification ability of the soil. The increase in copper content in acidic podzolic soils is accompanied by a decrease in the amount of mineral nitrogen. However, in soils with a high humus content, cadmium and lead have contributed to the increase in the amount of mineral nitrogen. High doses of cadmium and zinc suppress the urease and dehydrogenase activity of the soil.

As the content of heavy metals increases, the spatial variability of nitrogen-fixing activity decreases. In soils where the concentrations of heavy metals are more than ten times the base (natural), the variability of nitrogen-fixing activity is significantly lower.

When soil is contaminated with cadmium, the release of CO_2 from the soil is reduced by 2-3.5 times, and when chromium is contaminated, it is reduced by 2-6 times. According to the strength of the effect on the number of nitrifying bacteria in the soil, heavy metals can be distributed in the following order:

Cd> Ni> Cr

The increased content of heavy metals in the soil inhibits the processes of nitrogen transformation and leads to a decrease in the activity of nitrifiers, which slows down the processes of transformation of nitrogenous substances and reduces the utilization of mineral forms of nitrogen (Hu et al., 2002; You et al., 2008).

The microbial coenosis of the soil adapts to the pollution of the soil with heavy metals depending on their concentration. At certain concentrations, the mechanism of adaptation is not functional and the microbial community undergoes significant changes. Under the influence of increasing concentrations of cadmium and chromium, the number of nitrifiers in chernozem decreases and the activity of cellulose bacteria decreases, while under the influence of nickel, the activity of cellulose bacteria does not change (Đukić et al., 2007, 2020).

Therefore, a characteristic feature of soils that are not contaminated with heavy metals is the wide spatial and temporal variability of the application of all parameters of microbial coenosis functioning. During soil pollution, which is several times higher than the basic (natural), certain indicators of enzyme activity change. The biomass of the amylolysis microbial community grows. When the soil is polluted with heavy metals, which are an order of magnitude above the basic one, the biochemical activity of soil microorganisms decreases and the degree of dominance of the amylolysis microbial community that actively functions in the soil is redistributed. When the soil is polluted with heavy metals, which exceed the basic by one or two orders of magnitude, there is an obvious decrease in the whole group of indicators. There is an absolute dominance of one type of micromycetes and the participation of epiphagous yeasts is growing rapidly. When soil is contaminated with heavy metals, which is three orders of magnitude higher than the basic one, there is a sudden change in all microbiological processes, as well as the death of microorganisms that are normal for unpolluted soils. At the same time, the dominance of micromycetes increases (Đukić, Mandić, 2000). If the content of heavy metals in the soil increases four or more times above the basic one, there is a sharp decrease in the microbiological activity of the soil, which borders on the complete death of microorganisms.

The mutagenic activity of a large number of heavy metals was also determined: cadmium, copper, mercury, lead, chromium, nickel and manganese. Mutations in microorganisms, caused by heavy metals, are manifested by the appearance of resistance to these elements. For example, the formation of resistance in rhizobium to cadmium is due to the mutant action of that metal. However, at a concentration of less than 10 mg /L, cadmium stimulates the growth of rhizobium. Soils that contain the highest amounts of cadmium, despite their high adsorption capacity, exhibit the greatest mutagenic effect compared to less polluted soils.

Thus, the most toxic elements for soil microorganisms are mercury and cadmium, while nickel lead and copper are less toxic. Because heavy metals exhibit high toxicity in plant tissues (Kastori, 1997). for food products, the minimum values of MDK of heavy metals are provided.

CONCLUSION

Based on the results of research related to the role of intensive industrialization, urbanization, transport and chemicalization of agriculture in environmental pollution by heavy metals and their impact on soil microorganisms, the following conclusions can be drawn:

- numerous technogenic and anthropogenic agents have led to, often, a significant increase in heavy metals in the environment;
- in low concentrations heavy metals can stimulate the development of microorganisms, and in higher concentrations they lead to a decrease in their number and a change in the qualitative composition of their species;
- some microorganisms, especially some micromycetes have the role of

hypercumulators of heavy metals, thus leading to a decrease in their concentration in the environment;

- chromogenic microorganisms are especially characterized by the hyperaccumulation ability of heavy metals;
- many microorganisms appear as indicators of the type and degree of environmental pollution by heavy metals.

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LITERATURE

Balyaeva O.N., Haynes R.J., Birukova O.A. (2005): Barley yield and soil microbial and enzyme activities as affected by contamination of two soils with lead, zinc or copper. Biol Fertil Soils 41:85–94

Djukić, D., Vsevolod, J., Semenov, A., Iutinska, G., Selicka, O. Ecological biotechnology, book I, II. Faculty of Agriculture in Čačak, 2018, p. 1598

Dragutin A. Djukić, Aleksandar M. Semenov, Mitar V. Lutovac, Leka G. Mandić, Galina A. Iutinska, Valenlin S. Podorovski. Soil ecosystems - pollution and cleanup. Faculty of Agriculture, University of Kragujevac, 2020, p.628.

Đukić, D., Đorđević, S., Trifunović, B., Mandić, L., Marković, G., Mašković, P., Tanasković, S., Brković, D. Bioindication and biotesting of environmental pollution. Budućnost DOO, Novi Sad, 2013, p. 337.

Đukić, D., Jemcev, V.T., Kuzmanova, J. Biotechnology of soil, Budućnost, Novi Sad, 2007, p. 529.

Đukić, D., Mandić, L.: Microorganisms and Technogenic Polution of Agroecosystem. Acta Agriculturae Serbica, 5(10): 37-44.

Gavrilesca M. (2004): Removal of heavy metals from the environment by biosorption. Eng. Life Sci. 4(3): 219-232.

Govedarica, M., Milošević, N., Jarak, M. Heavy metals and soil microorganisms. Heavy metals in the environment. Editor R. Castori. Scientific Institute of Field and Vegetable Crops. Novi Sad, 1997, p. 153-193.

Guzev, V.S., Levin, S.V., Seletskii, G.I., *et al.*, The Role of Soil Microbiota in Reclamation of Oil-Polluted Soils, in Mikroorganizmy i okhrana pochv (Microorganisms and Soil Protection), Zvyagintsev, D.G., Ed., Moscow: Mosk. Gos. Univ., 1989, pp. 121–150.

Hu Z.Q., Chandran K., Grasso D., Smets B.F. (2002): Effect of nickel and cadmium speciation on nitrification inhibition. Environ. Sci. Technol. 36: 3074–3078

Kastori, R., Petrović, N. Influence of heavy metals on plants. Heavy metals and pesticides in soil. Editor R. Castori. Faculty of Agriculture, Novi Sad and Institute of Field and Vegetable Crops, Novi Sad, 1993, pp.55-73.

Kastori, R., Petrović, N., Arsenijević-Maksimović, J. Heavy metals and plants. Heavy metals in the environment. Editor R. Castori. Scientific Institute of Field and Vegetable Crops. Novi Sad, 1997, p. 195-259.

Mikanova O. (2006): Effects of heavy metals on some soil biological parameters. J Geochem Explor 88:220–223

Simon A. Levin. The problem of pattern and scale in ecology. Department of Ecology and Evolutionary Biology, Princeton University, Princeton, New Jersey 08544-1003 USA, and Section of Ecology and Systematics, Cornell University, Ithaca, New York 14853-2701 USA, 1989.

Verešbaranji, J., Šovljanski, R., Pucarević, M., Kastori, R. Pollution of the soil of Vojvodina with pesticides and their metabolites. Heavy metals and pesticides in the soil. Editor R. Castori. Faculty of Agriculture, Novi Sad and Institute of Field and Vegetable Crops, Novi Sad, 1993, pp.223-259.

Wang Y., Shi I., Wang H., Lin Q., Chen X., Chen Y. (2007): The influence of soil heavy metals pol-lution on soil microbial biomass, enzyme activity, and community composition near a copper smelter. Ecotoxicol Environ Saf 67:75–81

You S.J., Tsai Y. P., Huang R.Y. (2008): Effect of Heavy Metals on Nitrification Performance in Different Activated Sludge Processes. Journal of Hazardous Materials 165(1-3):987-94

Zafar S., Aqil F., Ahmad I. (2007): Metal tolerance and biosorption potential of filamentous fungi isolated from metal contaminated agriculture soil. Bioresour. Technol. 98: 2557-2561.