World Journal of Environmental Biosciences
Available Online at: **www.environmentaljournals.org**

Volume 13, Issue 3: 1-7

https://doi.org/10.51847/evfEMeqisK

ISSN 2277- 8047

Studying the Effectiveness of Phytoremediation in the Purification of Soils Contaminated with Heavy Metals

Jhonatan da Silva[1], Gabriel Bachega Rosa[2], William Gustavo Sganzerla[3*], Jocleita Peruzzo Ferrareze[2], Flávio José Simioni[1], Mari Lucia Campos[1]

[1]Center of Agroveterinary Sciences (UDESC-CAV), University of the State of Santa Catarina, Lages, SC, Brazil.
[2]Federal Institute of Education Science and Technology (IFSC), Lages, SC, Brazil.
[3]School of Food Engineering (FEA), University of Campinas (UNICAMP), Campinas, SP, Brazil.

ABSTRACT

Waste chemicals cause soil pollution and increase concerns about the environment. Among these waste materials, heavy metals have significant physiological effects on living organisms due to their indestructibility. Due to the lack of decomposition of heavy metals in the environment, there is a need to remove them from the environment. Considering the very high costs of physical and chemical methods, efforts are being made to introduce and use cheaper methods. In this study, an attempt has been made to introduce a new method using the potential of plants to remove soil pollution. The most obvious disadvantages of this method are the following: limited to sites with low and medium pollution, shallow roots, low biomass production, low bioavailability of metals in the soil (especially calcareous and young soils) in dry areas and Semi-dry, and time-consuming. According to the results obtained from various studies, the following are suitable solutions to overcome these problems: choosing suitable species, using bacteria resistant to heavy metals and stimulating plant growth, strengthening the root system, more biomass production, and increasing the bioavailability of metals by plants. The use of microbial inoculation helps plant species to efficiently remove heavy metals from the soil. The application of the phytoremediation technique has been less used so far and due to the ignorance and carelessness of some people, it has never been used as an effective method in the purification of heavy metals in contaminated soils. Therefore, it is necessary to introduce and replace plants and apply new strategies based on the investigation of the cooperation of plant-microbial communities.

Keywords: *Waste chemicals, Pollution, Plant remediation, Purification, Heavy metals*

Corresponding author: William Gustavo Sganzerla
e-mail ✉ sgazerla.william@gmail.com
Received: 02 April 2024
Accepted: 19 July 2024

INTRODUCTION

Soil is the substrate on which the survival of millions of people depends, and from a global perspective, soil is considered the third major component of the environment. Considering the limited soil resources, soil pollution is one of the most important environmental problems in countries. If the contaminated soil is not cleaned, the pollutants will gradually penetrate deep into the soil, and in addition to the soil contamination, it will cause the contamination of the underground water table, which is one of the most important sources of water supply in many countries of the world. In this way, one of the most important challenges in the world is fighting the pollution of soil resources on the one hand and rehabilitating and cleaning polluted places on the other hand (Rodríguez-Espinosa *et al*., 2021; AbdelRahman, 2023; Tindwa & Singh, 2023).

The issue of soil pollution by waste chemicals has increased concerns about the environment. Among them, heavy metals are known to be important even in low concentrations due to their indestructibility and the physiological effects they have on living organisms. Also, when heavy metals accumulate in plant tissues, they often directly affect pigments or enzymes by replacing other essential nutrients and disrupting their function. Or indirectly, the presence of heavy metals by destroying the cell structure causes oxidative stress and increases the production of reactive oxygen species (ROS) (Georgio *et al*., 2015; Liu *et al*., 2016; Skrypnik, *et al*., 2021; Pati *et al*., 2022). In addition to natural processes, heavy metals can cause soil pollution through human resources such as mining activities, waste, and garbage burial, excessive use of chemical fertilizers, fossil fuels, and the like (Cui *et al*., 2023; Panqing *et al*., 2023).

According to the studies, the excessive growth of cities in recent decades on the one hand, and the lack of sewage collection systems on the other hand have caused agricultural lands to become receivers of municipal sewage and industrial sewage of some industries. Another major issue is the use of sewage sludge in agricultural lands, which contains heavy metals (Iticescu *et al*., 2021; Duan & Feng, 2022). On the other hand, the use of phosphate fertilizers in agricultural lands causes a decrease in soil pH and the release of lead heavy metals, chromium, cadmium, and arsenic (Atafar *et al*., 2010; Wang *et al*., 2022). These factors cause the bioaccumulation of heavy metals in plants and finally, they are transferred to humans and animals through the food chain (Atafar *et al*., 2010; Wei *et al*., 2020; Naz *et al*., 2022).

Other factors of environmental pollution with heavy metals are mining activities, abandoned sulfide mines, acidic mine drainage, and abandoned tailings. Tailings have a high concentration of elements that are exposed to water and wind erosion and act as a permanent source of metal pollution to their environment, which are released under special environmental conditions and enter water and soil sources. Also, waste leachate usually has a high concentration of heavy metals, so the amount of heavy metals is several times that of normal soils (Olías & Nieto, 2015).

The application of the phytoremediation technique has been less until now and due to the ignorance and carelessness of some people, it has never been used as an effective method in the purification of heavy metals in contaminated soils. Therefore, it is necessary to introduce and replace plants and apply new strategies based on the investigation of the plant-microbial community's cooperation, so that we can take steps in the path of expanding new plant treatment to reduce the risk of soil health and increase food security effectively and economically.

The importance and necessity of phytoremediation

Heavy metals do not decompose in the environment, so it is necessary to remove them from the environment. On the other hand, the exorbitant costs of physical and chemical methods have led to efforts to find cheaper methods. Using the usual physical and chemical treatment methods in cases where the concentration of heavy metals is low, they are not economical and affordable and may even cause the production of secondary effluents, which in turn will lead to more treatment problems (Jacob *et al*., 2018; Zhou *et al*., 2023). Therefore, researchers have established a new method using the potential of plants to remove soil pollution and preserve this national capital. The high level of heavy metals in plants can have serious effects on the growth and development of plants, but some plants by developing special mechanisms can accumulate heavy metals in high concentrations, which are called hyperaccumulating plants. Hypertrophic plants can store 100 times more metals than non-hypertrophic plants. Phytoremediation is an effective method without the need for expensive equipment and specialized people, compatible with the environment, and applicable on a wide scale. Processes used in the phytoremediation of heavy metals are presented in **Figure 1**.

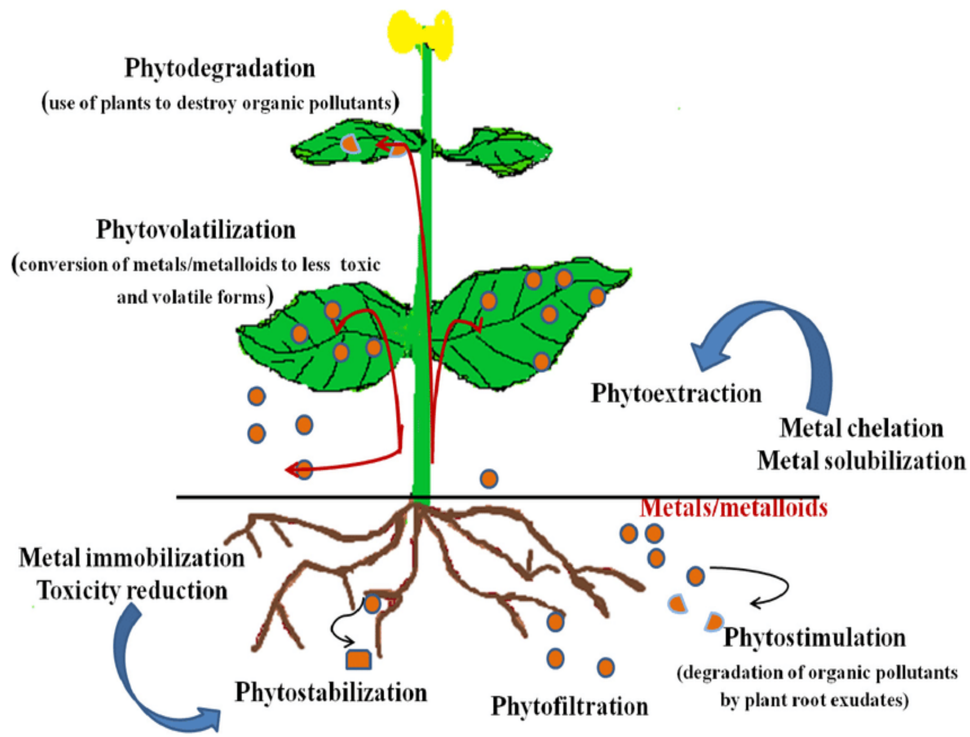

Figure 1. Processes used in phytoremediation of heavy metals.

In addition, the presence of vegetation on the soil surface prevents soil erosion and waste and dust generation. By using plants and planting them in polluted soils and applying new techniques of this method, a considerable percentage of heavy metals are absorbed by plants and removed from the environment. Despite the advantages of using plants in the purification of organic and inorganic pollutants, the following are the most obvious disadvantages of this method: limited to sites with medium and low pollution, low biomass production, and few roots. Depth, low bioavailability of metals in soil (especially calcareous and young soils) in arid and semi-arid areas, and time-consuming (Mahajan & Kaushal, 2018; Yan *et al*., 2020; Nedjimi, 2021). These unavoidable limitations force researchers to modify traditional approaches and apply new techniques of phytoremediation to minimize limitations and ensure widespread use of phytoremediation. The selection of suitable species for phytoremediation of heavy metals is one of the critical stages of phytoremediation. In high-yielding plants, two very important factors must be investigated and evaluated: the range of tolerance of the plant to the elements and the ability of bioaccumulation in different organs of the plant (Sarwar *et al*., 2017; Durante-Yánez *et al*., 2022). Another solution to overcome the mentioned problems in plant remediation is the use of bacteria resistant to heavy metals and plant growth promoters to strengthen the root system, produce more biomass, and increase the bioavailability of metals by plants. Growth-promoting bacteria increase the solubility of elements such as organic and inorganic phosphates and facilitate their absorption and supply enzymes needed by the plant. In addition, bacteria are effective in purifying heavy metals from the soil by using different mechanisms including biosorption, bioprecipitation, accumulation, transformation of heavy metals, increasing metal solubility, etc. Therefore, the use of micro-inoculation will help plant species to efficiently remove heavy metals from the soil (Sarwar *et al*., 2017; Babu *et al*., 2021; Sharma *et al*., 2023).

Importance and economic and social justification of phytoremediation

Soil is the source of income, production and the basis of all material civilizations and one of the most important and valuable resources of nature, and life on earth will not be possible without healthy soil. In some parts of the world, soils contaminated with metals and chemicals such as lead, asbestos, and sulfur are undesirable for the production of agricultural products and cannot be used after harvesting due to the high levels of toxicity of the products. This leads to huge economic losses. For example, in the agricultural sector, in China, about 12 million tons of contaminated seeds are buried annually, and the loss of Chinese farmers is estimated at 2.6 billion dollars. In addition, the pollutant enters the food chain through plants and harms the health of animals and humans (Wan *et al*., 2016; Sharma *et al*., 2023).

Calculating the benefits of treating farmland is rarely done, and there is no readily available market value for farmland because it cannot be bought or sold. Therefore, the value of farm soils can be calculated indirectly. Indirect values of phytoremediation can include improving soil performance to produce quality agricultural products, food security, soil health, prevention of soil erosion, social benefits (reuse of land for green space use), environmental aspects (soil protection agriculture, protecting habitats for sensitive species), and economic benefits (creating jobs, increasing land value) (Wan *et al*., 2016). Decontamination of soils is a long-term goal that can simultaneously keep farmers' income at a level comparable to pre-treatment conditions. In fact, in soils contaminated with heavy metals, along with the purification of contaminated soils, economic exploitation can also be achieved and the motivation of farmers and industrial managers to purify the land can be increased. This technology can be used with the two goals of purifying soils contaminated with heavy metals and economic and agricultural productivity. If this action is not done, not only the problem of pollution will remain, but the burden of land pollution will also increase every day, and the land will lose its fertility over time. On the other hand, this contamination will enter the food chain and endanger food safety. The investigated plant species can include three agricultural, herbaceous, and ornamental groups. The advantages of the phytoremediation technique are presented in **Figure 2**.

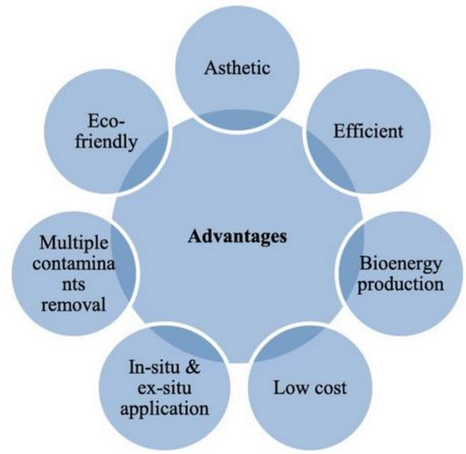

Figure 2. Advantages of phytoremediation technique.

Another group of plants for planting in lands contaminated with heavy metals are fodder plants such as fescue, spruce, timothy grass, ryegrass, garden grass, and wheat grass. These plants have a suitable yield of 5-10 tons per hectare and can be fed to livestock as fodder. Also, candidate microorganisms for soil cleaning can be grown and produced as dry bacterial products on a suitable carrier to stabilize the microorganism for use on an industrial scale. On the other hand, biological purification of pollution is one of the most economical and effective purification methods, and other physical and chemical methods are not economical and economical in cases where the heavy metal concentration is low. Since plants can grow on a large surface and absorb toxic metals at a lower cost than other biological treatment methods, and unlike artificial systems, they are very economical. So in most cases, the costs are 50% lower than other methods such as excavation (Bandehali *et al*., 2021; Boi *et al*., 2023; Guidi Nissim *et al*., 2023).

Optimization and plant remediation strategies

With the following suggestions, it is possible to produce healthy food in lands contaminated with heavy metals, produce healthy fodder in lands contaminated with heavy metals, manage pastures in line with revitalizing vegetation and animal health, clean agricultural lands of heavy metals, use alternative plants in agriculture with appropriate economic productivity, maintaining the health of pastures and livestock through the recommendation of alternative plants, identifying susceptible plants for phytoremediation, increasing the growth and biomass production of plants in conditions of metal stress, increasing the efficiency of plant extraction through increasing the dissolution and absorption of metals, reduction of health risk, as well as the identification of high added value and high capacity of metal extraction from soil were achieved. **Figure 3** shows the optimization of an integrated phytoremediation system (IPS) for enhanced lead removal and restoration of soil microbial activities (Wang *et al*., 2022; Alsafran *et al*., 2023; Zulfiqar *et al*., 2023).

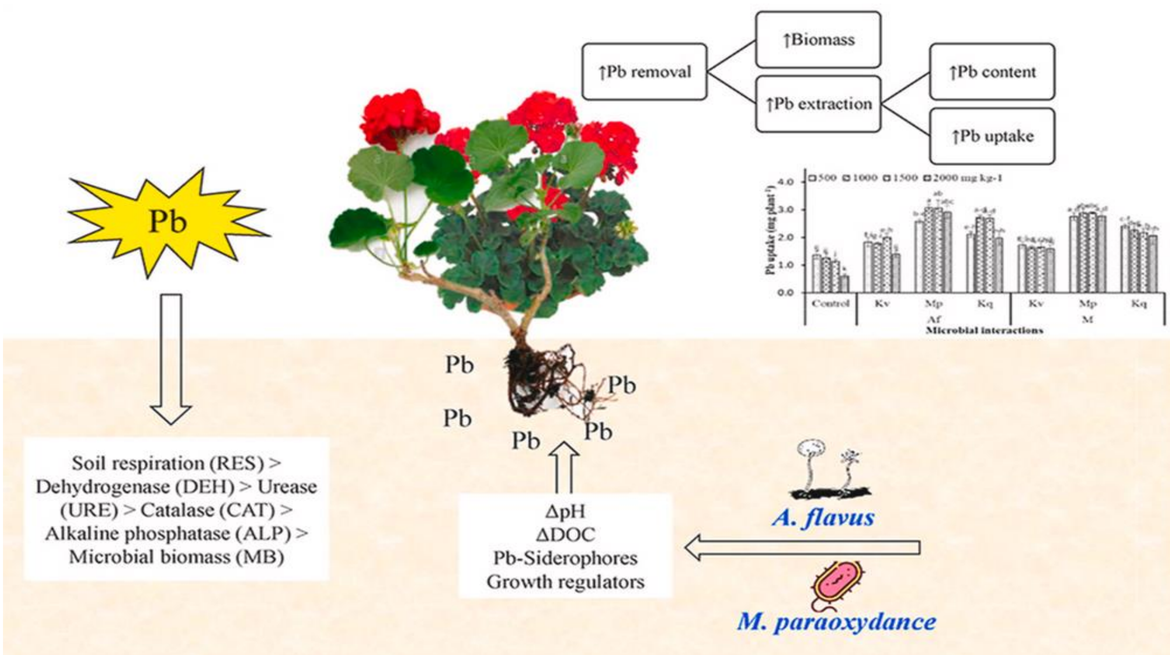

Figure 3. The optimization of an integrated phytoremediation system for enhanced lead removal and restoration of soil microbial activities.

Introducing suitable crops to replace cultivation in soils contaminated with heavy metals

Contamination of agricultural land with heavy elements is considered a serious risk for the production of healthy products in the world. Agricultural plants are considered an important communication bridge for the transfer of heavy elements from the soil to the human food chain due to the absorption of heavy elements from the soil. Even in low concentrations, these elements threaten human health. For this purpose, it is necessary to reduce the pollutants in the soil through their accumulation in the roots of plants or sedimentation in the area of the roots, and their transfer to the food chain by using biological stabilization techniques. Unlike other techniques, plant stabilization plant remediation does not remove metals from the soil, but by immobilizing them through absorption or deposition in the root zone, it reduces their risks to human health and the environment. Plants with high bioconcentration factor (BCF, ratio of metal concentration in plant roots to its concentration in soil) and low transfer factor (TF, ratio of metal concentration in stem to its concentration in root) are suitable for plant stabilization. The absence of a high concentration of metals in the stem eliminates the need to dispose of harvested plants (Rashid *et al*., 2023). In this project, sorghum, millet, and flax species are proposed for cultivation in agricultural lands to reduce the pollution load in crops and food safety.

Introduction of herbaceous plants to stabilize heavy metals in polluted soils

A lot of research has been done about the way and amount of contamination of herbal products and the side effects caused by their direct consumption. In this regard, the consumption of contaminated fodder plants by livestock and domestic animals has two perspectives. First, the use of contaminated fodder causes problems in livestock and domestic animals, such as reduced milk production and growth rate, reduced resistance to infections and infections, and impaired reproduction. Second, by consuming animal products, pollutants will enter the human food cycle. Also, due to the multiplicity of pollution industries and the ways of its transmission, currently, the best way to reduce these risks is to take seriously the way of feeding and controlling the ration of animals. Therefore, it is necessary to use specific plant species to immobilize pollutants in the soil through surface absorption and accumulation by the roots, absorption inside the roots or deposition in the root area, and physical stabilization of soils, or in other words plant stabilization. Also, plant stabilization reduces the mobility of pollutants and prevents their transfer to underground water and atmosphere (Yan *et al*., 2020; Raffa *et al*., 2021). Therefore, in this research, several types of fodder plants that have economic aspects and good performance, including *Onobrychis aucheri* Boiss, *Phleum pratense*, *Lemon Grass*, *Lolium perenne*, *Dactylis glomerata*, *Tall fescue*, *Agropyron desertorum*, and *Agropyron desertorum* in the direction of producing healthy fodder and revitalizing vegetation.

Introduction of high-yielding ornamental plants to purify soils contaminated with heavy metals

In recent years, plant-based environmental remediation technology has been widely pursued as a cost-effective in-situ strategy for cleaning metals from contaminated sites. In this project, plant extraction means the use of pollutant-absorbing plants to remove metals or organic pollutants from the soil through their accumulation in harvestable parts. Plant extraction involves planting plants repeatedly in contaminated soil to bring the metal concentration to an acceptable level (Awad *et al*., 2021; Hlihor *et al*., 2022). The following species are suggested for consideration: *Tagetes patula erecta*, *Chrysantemum maximum*, *Chrysanthemum indicum*, *Gladiolus grandiflorus*, and *Pelargonium graveolens*.

Investigating the absorption potential of heavy metals in the forage plants of the pastures around the mine

The plants around the mines are affected and damaged due to the release of heavy metals. On the other hand, feeding livestock in contaminated pastures around mines or fodder containing residues of heavy metals leads to the receipt of significant amounts of these elements by livestock, which can not only be stored in the animal's edible tissues but also through milk. Heavy metals play an important role in causing livestock poisoning. The amount of absorption of heavy metals can be very variable depending on the ability of plants to bioavail the metals in the system and other environmental conditions. Therefore, the potential of phytoremediation of palatable fodder plants around mines in different organs of alternative fodder plants proposed for animal feeding needs to be introduced. This method can also be a suitable method for improving and restoring areas in contaminated areas around mines. So that this process can lead to the re-establishment of vegetation in places where the vegetation has been lost due to the high concentration of metals (Castro-Bedriñana *et al*., 2021; Sladkovska *et al*., 2022).

Investigating heavy metal tolerant bacteria with plant growth stimulating properties

The use of bacteria can be a simple and effective strategy to increase growth and biorefinery activity. Bacteria have different mechanisms for decontamination of polluted environments through biosorption, bioaccumulation, leaching, biomineralization, and biotransformation. On the other hand, normally plant growth-stimulating bacteria lead to improved plant growth under stressful conditions. Some rhizosphere bacteria that directly and indirectly have beneficial effects on plants are called growth-promoting rhizosphere bacteria. These beneficial bacteria (Plant Growth Promoting Rhizobacteria) are also called yield-enhancing bacteria. Growth-promoting rhizospheric bacteria can directly play a role in increasing plant growth and performance by using different mechanisms. Increasing dissolution of low-soluble nutrients such as phosphorus, production of ACC-deaminase, production of plant growth hormones such as auxin, nitrogen fixation, and siderophore production (from the point of view of increasing iron absorption capacity) are among the most important direct mechanisms. In indirect mode, growth-promoting rhizospheric bacteria neutralize or moderate the harmful effects of plant pathogens by using different antagonistic mechanisms and thereby increase plant growth. Competition for the absorption of materials and occupation of suitable sites for the activity of pathogens, production of antibiotics, and production of siderophores (from the point of view of removing elements from the reach of pathogens), lytic enzymes and production of hydrogen cyanide are among the most important mechanisms used in this method (Ma *et al*., 2011; Oubohssaine *et al*., 2022).

Investigating bacteria capable of producing chelating compounds

The efficiency of plant extraction of metals from soils depends on the availability of metals for plants. The distribution of metals and the intensity of their bonding in the soil is influenced by metal species, age, and soil characteristics. If the availability of metals for absorption by plants is low, microorganisms can add chelating or acidifying agents to increase the availability of metals in the soil (Ma *et al*., 2011; Wang *et al*., 2022).

Feasibility of using bacteria to reduce the accumulation of heavy metals in crops cultivated in soils contaminated with heavy metals

Rhizosphere and endophytic bacteria (with greater capacity) in addition to modulating the harmful effects of biotic and abiotic stresses (resulting from heavy metals, salinity, etc.) on the plant can lead to a reduction in absorption and accumulation through different mechanisms. Heavy metals can also be found in plants or aerial organs. In addition to reducing the harmful effects of heavy metal stress on the plant, heavy metal-resistant bacteria can reduce the availability of heavy metals to the plant through different mechanisms in the soil. One of these mechanisms is surface absorption or bioaccumulation of heavy metals inside bacterial cells. Currently, heavy metal biosorption techniques are recommended for heavy metal removal because they are more effective, less expensive, and more environmentally friendly. Root endophyte bacteria prevent their transfer to the aerial organs of the plant (organs that can be harvested by humans or animals) by surface absorption of heavy metals (absorption of heavy metals on the bacterial cell wall), accumulation, complex formation, reduction, oxidation, etc. Finally, with this method, the risks of these elements for the health of humans and livestock can be reduced in agricultural lands (Xi *et al*., 2018; Letshwenyo & Mokokwe, 2020; Kurniawan *et al*., 2022).

CONCLUSION

In this study, an attempt has been made to introduce a new method using the potential of plants to remove soil pollution. The most obvious disadvantages of this method are the following: limited to sites with low and medium pollution, shallow roots, low biomass production, low bioavailability of metals in the soil (especially calcareous and young soils) in dry areas and Semi-dry, and time-consuming. According to the results obtained from various studies, the following are suitable solutions to overcome these problems: choosing suitable species, using bacteria resistant to heavy metals and stimulating plant growth, strengthening the root system, more biomass production, and increasing the bioavailability of metals by plants. The use of microbial inoculation helps plant species to efficiently remove heavy metals from the soil. The application of the phytoremediation technique has been less used so far and due to the ignorance and carelessness of some people, it has never been used as an effective method in the purification of heavy metals in contaminated soils. Therefore, it is necessary to introduce and replace plants and apply new strategies based on the investigation of the cooperation of plant-microbial communities.

ACKNOWLEDGMENTS: None

CONFLICT OF INTEREST: None

FINANCIAL SUPPORT: None

ETHICS STATEMENT: None

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