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REGULAR ARTICLE

Soil decontamination: bioremediation and phytoremediation

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Abstract

Practically all agro-industrial activities and the maintenance of cities have the potential to pollute and contaminate the environment. Thus, measures to mitigate the impacts of these activities must be evaluated, including bioremediation. In this sense, this work aimed to characterize the process of soil decontamination using bioremediation and phytoremediation. To this end, a bibliographic review based on scientific articles, books, dissertations, and theses was used. Bioremediation refers to the use of living organisms to remove, reduce, or neutralize pollutants from the environment. The technique can be performed on-site (in situ) or off-site (ex situ). Plants can also be used for bioremediation, characterizing, in this case, phytoremediation. Plants for phytoremediation must show tolerance to the contaminant and the ability to absorb and metabolize it. These plants include pigeon peas, pig beans, crotalaria, vetiver grass, and others. Bioremediation is expanding, requiring further studies.

Keywords

Sustainability; Environment; Phytoremediation.

Introduction

All agricultural and industrial activities are potential polluters and soil contaminants. However, measures can be adopted to minimize the level of such impacts to acceptable limits. The principle of sustainability – a concept that should be employed and implemented in all modern human activities – preconizes that production must be economically viable, ecologically correct, and socially fair (ZAMBERLAN et al., 2014).

Among natural resources, all are essential for the maintenance and balance of production chains, whether integrated or isolated. However, the structure and composition of some resources comprehensively affect certain processes and activities; among the most outstanding resources are water, air, and soil (BURMANN, 2010; FURTADO, 2010).

Due to several awareness movements and ways of approaching modern societies, air and water, even if still affected by pollution and inappropriate use, are moving towards a more sustainable uses, when compared to the soil. There is still a need to better deal with soil pollution and improper disposal of waste, something that seems to not yet be understood as an extremely negative action in social, economic, and environmental terms (ARAÚJO, 2002; OLMO, 2010; SANTOS, 2012; PEREIRA; CALGARO; PEREIRA, 2016).

In 2002, studies such as those by Carneiro, Siqueira, and Moreira (2002) already showed an increase in contaminated soils in Brazil, with heavy metals and in degraded areas. Studies involving ways to reduce or control soil contamination and degradation were under development since this period. One of the great examples related to soil contamination problems are dumping grounds and/or landfills.

An alternative to mitigate impacts related to soil contamination is the use of microorganisms in biological processes or plants in phytoremediation processes. Thus, bioremediation and phytoremediation (a type of bioremediation) are used to control such contamination (GASPARETO, 2009).

Bioremediation is based on the use of microorganisms to degrade toxic compounds, which will be transformed into neutral products or products that are less harmful to the environment. Phytoremediation, on the other hand, uses plants for the same purpose. Studies on the technique are expanding, among its benefits is the transformation of pollutants into organic waste, biomass, and/or inert by-products, which are all harmless from microbial metabolism, such as CO_2, CH_4, and organic salts (ALMEIDA; SILVA, 2010).

In this context, the present work aimed to gather information about bioremediation, in general, as a soil decontamination process, while focusing on phytoremediation, as well as to describe the mechanisms and steps of this form of decontamination.

Bioremediation

Bioremediation is a process in which living organisms such as microorganisms and/or plants (in this last case, it is called phytoremediation) have technological use in the

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removal or reduction (remediation) of pollutants in the environment. This process has been researched and indicated by the scientific community as a viable alternative to treat contaminated areas, such as surface water, groundwater, as well as soil, waste and industrial effluents in landfills and containment areas (SILVEIRA; TATTO; MANDAI, 2016).

Since the 1950s, several genera of bacteria and fungi that degrade contaminating compounds controlled in bioremediation have been isolated. However, the highlight for microbial consortia only came in recent years. Comparing these consortia to pure cultures, it is possible to comparatively demonstrate that its efficiency is much higher (JACQUES et al., 2007; WETLER-TONINI; REZENDE; GRATIVOL, 2010).

Although there is an indication of other types of technologies for the decontamination of polluted environments, such as physical and/or chemical processes, the biological process of bioremediation is a more viable alternative for the ecological issue, being also more effective for the treatment of these environments. Organic molecules that are difficult to degrade (recalcitrant) originate both naturally from the metabolism of living beings and from industrial technologies that are foreign to the environment, called xenobiotics (PEREIRA; FREITAS, 2012; CATARINO, 2016).

These molecules have been introduced into the environment since the 20th century, with a very wide range of compounds such as pesticides, dyes, polymers, plastics, drugs, and many others. These may be toxic to the environment and to living beings present in it, since they are not natural molecules of the metabolism of these beings. Among the impacts of xenobiotics, mutagenic and harmful effects, selective elimination, and changes in the structure of the ecosystem stand out (GAYLARDE; BELLINASO; MANFIO, 2005; HUBER, 2012).

There are several biotechnologies created to remove or reduce xenobiotics from the environment. The processes that make up bioremediation are mechanisms from the environment itself, or that were introduced into it (whether natural or genetically modified), showing the ability to transform these compounds into less aggressive ones or simpler compounds such as: CO_2, H_2O, NH_3, SO4-2, PO4-2 (GAYLARDE; BELLINASO; MANFIO, 2005; ROCHA, 2015).

On-site and off-site bioremediation

Bioremediation can be divided into two techniques that encompass several smaller ones. The first is *in situ* (on-site) bioremediation, which encompasses natural attenuation, biostimulation, bioaugmentation, biostabilization, bioventilation, phytoremediation, and landfarming. In this type, bioremediation is carried out in the soil of the contaminated area itself, generating lower costs with transport and storage of the contaminated material, since it is carried out on-site (JACQUES et al., 2007; WETLER-TONINI; REZENDE; GRATIVOL, 2010; SILVA, 2012). The other technique is called *ex situ* (off-site) bioremediation, which encompasses the use of bioreactors and composting, where soil bioremediation is carried out elsewhere. In terms of sustainability, on-site bioremediation is more sustainable than off-site (JACQUES et al., 2007; ALMEIDA; SILVA, 2010; WETLER-TONINI; REZENDE; GRATIVOL, 2010).

Each modality of bioremediation starts from a principle. However, one purpose is common to all modalities: to reduce soil contamination, converting or neutralizing pollutants. In this context, oxygen is considered the most critical metabolic factor in bioremediation. Thus, an important principle in this process is called bioventilation, which consists of intensifying the use of oxygen in the treatment of contaminated soil, by passing oxygen through it, in order to stimulate growth and microbial activity (REGINATTO; 2012; DUARTE, 2016).

The main advantages of bioventilation refer to its low cost, the use of higher concentrations of oxygen than the saturation provided by air, and the non-persistence within the environment. Among its disadvantages are toxicity to microorganisms and rapid decomposition in underground environments (ALMEIDA; SILVA, 2010; DUARTE, 2016).

Another principle of bioremediation is bioaugmentation, which uses the addition of microorganisms to increase the biodegradation of the pollutant. It can be performed using the autochthonous population of microorganisms (those present in the contaminated area itself) and it can also be done using microorganisms cultivated in a contaminated system (soil), from a stock culture (ANDRADE; AUGUSTO; JARDIM, 2010; DEON et al., 2012; JERÔNIMO et al., 2012). For bioaugmentation to be successful, microorganisms must have a high level of enzymatic activity, must be able to compete with the native population of the contaminated area, and must not produce toxic substances during biodegradation (OLIVEIRA, 2008; ALMEIDA; SILVA, 2010).

Some studies show that the competition of foreign microorganisms with native ones reduces the efficiency of the process. Therefore, preference should be given to native microorganisms. Brazilian legislation only allows the use of native microorganisms in remediation processes, as the incorrect use of foreign microorganisms can cause imbalance in the ecosystem. This technique has the main advantage of reducing the time of bioremediation (ANDRADE; AUGUSTO; JARDIM, 2010; PEREIRA; FREITAS, 2012).

Bioremediation stages

Bioremediation can be fragmented into different stages, following a logical and simple sequence, branching out during the course of the work. To start bioremediation, the nature of the contaminated environment must first be assessed (type of soil, water, etc.). Then, the contamination of the environment must be characterized (type and nature of the compound, quantity, distribution, and time) (FALEIRO; ANDRADE; REIS-JUNIOR, 2011; LIMA, 2012).

The next step consists of planning the type of bioremediation to be carried out, using biological, geological, geophysical, and hydrological analyses. The fourth step is to decide the type of bioremediation to use (on-site or off-site). Finally, a decision must also be made between bioremediation with microorganisms or with plants (phytoremediation) (GAYLARDE; BELLINASO; MANFIO, 2005; MORAIS FILHO; CORIOLANO, 2016).

At this point, each of the two paths presents its particularities. For phytoremediation, there is the selection and introduction of the proper plants that can be used for the process, or the introduction of genetically modified plants. For the use of microorganisms (general bioremediation), there is the option of biostimulation or bioaugmentation. The former uses native microorganisms that are degraders, being based on stimulating their metabolic activity, while the latter is based on the incrementation of more microorganisms into the contaminated area (GAYLARDE; BELLINASO; MANFIO, 2005; SILVEIRA; TATTO; MANDAI, 2016).

The introduced microorganisms can be of natural origin and can be the same ones from the contaminated area. Nevertheless, these microorganisms must be either produced in a culture medium and then added to the soil, or must be foreign to the soil, being different from the native ones. There is also the option of using GMOs (Genetically Modified Microorganisms). All these steps must be monitored and can/should be adjusted to improve the process (GAYLARDE; BELLINASO; MANFIO, 2005; PEREIRA; FREITAS, 2012).

Phytoremediation

Phytoremediation is a technique that goes hand in hand with bioremediation, often being included within it. Its use has been studied mainly in Europe and the United States (PIRES et al., 2003).

Phytoremediation consists of the use of plant systems such as creeping and aquatic plants, trees, and shrubs, together with their microbiota and soil softeners (fertilizers, correctives, organic matter, etc.). These factors are still supported by the use of agronomic practices to remove and immobilize contaminants, trying to make them harmless to the environment. Natural or acquired selectivity is used for the selection of plants that are to be used in phytoremediation (COUTINHO; BARBOSA, 2007; ALMEIDA; SILVA, 2010; MENDES, 2013; SILVA et al., 2019).

Plant roots modify the physical, chemical, and biological structure of the soil, stimulating the local microbiota and degrading compounds. Phytoremediation is influenced by pH, soil texture and porosity, salinity, climate, as well as the type and concentration of pollutants. Despite being low cost, phytoremediation has the disadvantages of taking a long time to obtain results (depending on the plant cycle). The plant can also die when the pollutant concentration is higher than what it is tolerated by it, and the fact that it absorbs pollutants can generate undesirable consequences in the food chain (ALMEIDA; SILVA, 2010; MARQUES; AGUIAR; SILVA, 2011).

Plants for Phytoremediation

Phytoremediation plants, in addition to tolerance, must have the ability to absorb and metabolize contaminating compounds, only then can the plant effectively carry out the phytodegradation and/or phytotransformation of these compounds. Phytoremediation plants seek to absorb and, thus, remove contaminating compounds from the soil until their levels are acceptable. Thereafter, the absorbed compounds are transformed into non-toxic or less toxic compounds. The importance of this process is evident in agricultural cultivation systems with crops in succession or rotation (PIRES et al., 2003; MENDES, 2013).

Despite the various works in the area, studies are still lacking for many compounds, whose phytoremediating plants are still unknown. Among some examples of phytoremediating plants, there are pigeon pea, jack bean, dwarf pigeon pea, crotalaria juncea, vetiver grass, and several others. This emphasizes that a plant can be a phytoremediator of one compound and not another (MENDES, 2013; ALMEIDA; SILVA, 2010).

Some plants used as phytoremediators are endemic to polluted soils, so it can be thought that they have developed some mechanism of ecophysiological adaptation, which manifests itself in the form of resistance to soil contamination (CARNEIRO; SIQUEIRA; MOREIRA, 2002; COUTINHO; BARBOSA, 2007; RODRIGUES et al., 2016). The tolerant plants have, as a remarkable characteristic, the great development of roots in contaminated soils. This root production is fundamental in the phytostabilization of the contaminated areas, since the development of the root system promotes erosion control, reduction of leaching, and helps in the microbial activity of the soil (CARNEIRO; SIQUEIRA; MOREIRA, 2002; QUEGE; ALMEIDA; UCKER, 2013).

Among phytoremediating plants, vetiver grass (*Vetiveria zizanioides* (L.) deserves to be highlighted. It is characterized as a perennial grass, which develops in different climates, reaching up to 1.5 m in height, and producing a large amount of biomass. It is resistant to pests, diseases, frost, water deficit, and fire. Its propagation occurs only by seedlings and its roots reach up to 3 m deep. Vetiver grass also tolerates rainfall between 300 to 3,000 mm per year and temperatures between -9º to 50º C. Its pH can also vary from 3 to 10, being tolerant to toxicity and salinity, being also able to grow even with low levels of nutrients in the soil (TAVARES, 2009; MIRANDA-SANTOS; OLIVEIRA, 2012).

Mechanism

Phytoremediation follows the same steps as bioremediation, with a few changes. Phytoremediation is used in various types of contamination, with organic and inorganic substances, pesticides, explosives, and especially heavy metals (PIRES et al., 2003; SANTOS et al., 2011). The use of phytoremediation is based on the natural or artificial selectivity of plants, which are tolerant to contaminants. The compounds can be translocated to different plant tissues, for subsequent volatilization, or even undergo total or partial degradation (MARQUES; AGUIAR; SILVA, 2011; SOUZA, 2017).

The ability to metabolize contaminating compounds is the principle of phytodegradation. There is also phytostimulation, which stimulates the microbiota by releasing root exudates. The absorption of compounds is affected by their chemical properties, the environmental conditions, or the characteristics of the plant species used (SOUTO, 2014; SOUZA, 2017). During translocation, the compound must pass through the endoderm symplast, the transpiration flow is what promotes the transport to the aerial parts of the plant, which will lead to phytodegradation (PIRES et al., 2003; MEJÍA et al., 2014).

Heavy metals

It is usually more difficult to work with organic contaminants, since inorganic contaminants, such as heavy metals, are more easily quantified and do not generate intermediates during their metabolization, as occurs with organic compounds (PIRES et al., 2003; MUNIZ; OLIVEIRA-FILHO, 2006; VIRGA; GERALDO; SANTOS, 2007; SOUTO, 2011; RODRIGUES, 2016). Heavy metals occur naturally in the soil, examples of which are zinc (Zn), cobalt (Co), and copper (Cu), which play an important role in the nutrition of plants and animals. Still, other known heavy metals have deleterious effects on part of the ecosystem, such as arsenic (As), selenium (Se), cadmium (Cd), and lead (Pb)

(SOARES, 2004; SILVA; VITTI; TREVIZAM, 2007; SOUZA; MORASSUTI; Deus, 2018).

Usually, these metals are found in quantities that do not pose risks. Yet, human action – mainly industrial – has changed this scenario, increasing the concentration of heavy metals in several different ecosystems (DIAS-JUNIOR et al., 1998; QUINÁGLIA, 2012; RIBEIRO, 2013). This accumulation raises concern about environmental safety since they can become toxic to plants as well as soil microbiota and can also be inserted into the food chain. The sensitivity that plants and organisms have to heavy metals can vary, however, reducing the concentrations to harmless levels is fundamental (SILVA; VITTI; TREVIZAM, 2007).

Conclusions

In general, even though the soil decontamination techniques presented are not so recent, they only started to gain greater prominence in recent decades. This prominence is due to the benefits both in financial aspects and/or time. In addition to this appeal, more sustainable results can be obtained with such practices. Bioremediation and phytoremediation are considered alternative techniques for soil decontamination that have a promising future.

This work made it possible to learn more about bioremediation techniques with a focus on phytoremediation, in addition to describing its importance for the environment that receives more and more industrial contaminants. Through these techniques, it is possible to reduce the environmental impact that human activity has caused to the planet. Still, further studies are lacking on processes and organisms (or plants) that can be used and applied in these processes.

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