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Bioremediation an Optimistic Technology for Pollution

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When pesticides are used, a part of them remains in the soil, and the accumulation affects the microorganisms living there. Human exposure can occur through the ingestion of pesticide-contaminated water and food, the inhalation of pesticide-contaminated air, and directly from occupational, agricultural, and household use. The pesticides can enter the human body by dermal, oral, eye, and respiratory pathways. The toxicity of pesticides depends on the electronic properties and the structure of the molecule, dosage, and exposure times.

For these reasons, the residual pesticide concentration present in the soil must be reduced, and effective remediation techniques must be used to do this. An ecofriendly, cost-effective, rather efficient method is bioremediation, which is an alternative to more expensive and toxic approaches, such as chemical and physical methods. In biodegradation, the removal can be achieved by exploiting the microbial activity of microorganisms. The microorganisms, primarily bacteria, or fungi [transform pesticides into less complex compounds, CO_2, water, oxides, or mineral salts, which can be used as carbon, mineral, and energy source. In these reactions, the enzymes have an important role since they act as catalyst.

Several techniques are available for the biodegradation of pesticides, which could develop in aerobic or anaerobic conditions based on types of microorganisms. Moreover, the bioremediation techniques can be divided into three categories depending on where the remediation treatment is done, namely in situ, ex situ, or on-site.

In the in-situ approach, the treatment is involved in the contaminated zone, and usually, the process is aerobic. The main in situ techniques are natural attenuation, bioaugmentation, bio stimulation, bioventing, and disparaging. In the ex-situ methods, the contaminated soil is removed from polluted sites and transported to other places for treatment. Bioreactors, composting, landfarming, and bio piles are ex situ treatments. The on-site approach consists of the treatment of polluted soil on the surrounding site, to say the soil is removed from its original position but cleaned up in the neighbourhood without any impact due to its transport.

Further studies have explored the role of bioinformatics and machine learning in predicting and optimizing bioremediation processes. By analysing large datasets on microbial genomes and environmental conditions, researchers can identify key factors that influence bioremediation efficacy and tailor interventions more precisely.

Bioinformatics and Computational Modeling: Bioinformatics tools and computational models are being used to predict the behaviour of microbial populations in response to environmental conditions and contaminant exposure and these techniques can be explored to the maximum. Bioinformatics, IOT, Biosensors, learning tools can aid in the design of optimized bioremediation strategies and the prediction of long-term treatment outcomes [1]. According Srinivasan et.al 2024 nano biosensors can be used to detect pesticides in the field and this technology can also be suitably modified, explored and exploited in bioremediation.

Bio stimulation and Bioaugmentation: Bio stimulation techniques, such as the addition of nutrients or electron acceptors, can enhance microbial activity and accelerate contaminant degradation rates in bioremediation systems. Similarly, bioaugmentation involves introducing exogenous microorganisms with specific metabolic capabilities to boost biodegradation processes in contaminated environments [2].

Advanced Monitoring Technologies: Research into advanced monitoring technologies, such as molecular biomarkers, stable isotope probing, and remote sensing techniques, is enhancing our ability to track microbial dynamics and contaminant transformation processes in real time. The integration of Artificial Intelligence (AI) and Internet of Things devices offers potential for experimentation, with the goal of making these technologies more cost-effective and scalable challenges and leveraging emerging technologies, bioremediation holds significant promise as a cost-effective and environmentally sustainable approach for addressing a wide range of contaminated sites [3]. Furthermore, by merging scientific innovation with practical application, bioremediation emerges as a sustainable strategy to restore ecosystems, protect public health, and mitigate global climate change impacts and also to address the pressing urgency for bioremediation in present environmental context.

The bioremediation system is the use of microorganisms (bacteria, fungi, yeast, and algae) or microbial products to degrade, reduce, or remove pollutants in the environment although in some cases plants are also utilized for this purpose called phytoremediation. When bioremediation occurs, enzymes produced by microorganisms modify toxic pollutants by changing the chemical structure of pollutants. This event is called biotransformation. In many cases, biotransformation leads to biodegradation, when toxic pollutants are degraded, the structure becomes simpler, and ultimately becomes harmless and non-toxic metabolites, that called mineralization.

Bioremediation is an innovative and optimistic technology that can be used to remove and reduce heavy metals from polluted water and contaminated soil. Because of cost-effectiveness and environmental compatibility, bioremediation using microorganisms has an excellent potential for future development [4]. A diverse range of microorganisms, including algae, fungi, yeasts, and bacteria, can function as biologically active methylators, capable of modifying toxic species. Microorganisms play a crucial role in heavy metal bioremediation. Nanotechnology may minimize industry expenses by producing environmentally friendly nanomaterials to alleviate these contaminants [7].

Heavy metal like cadmium effects the biomarkers in guppy fish [5]. Endosulphan effects liver of albino mice [6]. The use of microorganisms in nanoparticles synthesis gives green biotechnology a positive impetus to cost reduction and sustainable production as a developing nanotechnology sector.

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