ROLE OF SOIL MICROBES IN MAINTAINING HEALTHY SOIL ENVIRONMENT

Abstract

Pesticides are chemical compounds used to eliminate pests, with herbicides being especially poisonous to weeds, making them useful for protecting crops against invasive species. However, the excessive and long-term use of these chemicals has resulted in serious issues such as soil, water, and, to a lesser degree, air pollution, which has a negative impact on the ecosystem and food chain. Soil contamination caused by residual pesticide concentrations frequently exceeds regulatory allowed limits. As a result, the task is to lower these chemical levels and develop agriculturally viable soils for producing environmentally friendly crops. Bioremediation, which employs the microbial metabolism of indigenous microorganisms, is a more environmentally friendly, cost-effective, and efficient alternative to physical and chemical techniques. There are several biodegradation strategies available, each based on bacterial, fungal, or enzymatic processes.Regulations on pesticide use are closely related to their environmental impacts. Countries now implement regulations to restrict pesticide consumption, ban the most harmful ones, and define acceptable concentrations in the soil. However, this variability in regulations leads to diverse perceptions of the toxicology of these compounds, resulting in different market values for crops grown in different regions. This chapter provides an overview of bioremediation methods for soils contaminated with commercial pesticides, considering the characteristics, classification, toxicity, and relevant legislation in force around the world.

Keywords: Pesticides, contamination, soil pollution, Bioremediation, chemicals.

Authors

Pushap Lata
Department of Zoology
Chaudhary Bansi Lal University
Bhiwani, Haryana, India

Jyoti Dalal
Department of Zoology
Chaudhary Bansi Lal University
Bhiwani, Haryana, India

Meenu Lakhlan
Department of Zoology
Chaudhary Bansi Lal University
Bhiwani, Haryana, India

Mamta Tirdia
Department of Zoology
Chaudhary Bansi Lal University
Bhiwani, Haryana, India

Lalita Gupta
Department of Zoology
Chaudhary Bansi Lal University
Bhiwani, Haryana, India

I. INTRODUCTION

Soil science is the scientific study of soils as a natural resource. It encompasses various disciplines such as geology, biology, chemistry, and physics to understand the formation, composition, properties, and functions of soils (Plante et al., 2009). Soil scientists analyze soil samples, conduct experiments, and study soil processes to gain insights into its role in supporting life on Earth. India is a agriculture based country so for the most of the people agriculture is the primary source of income. In Agriculture, soil is the foundation, providing nutrients, water-holding capacity, and physical support for plant growth. Soil science helps farmers understand the fertility and nutrient requirements of different crops, leading to improved agricultural practices and increased food production. Soil plays a crucial role in environmental processes in many ways for example it acts as a filter for water, purifying and storing it. Soils also act as a sink for carbon, helping mitigate climate change by sequestering carbon dioxide from the atmosphere (Gregory., 2006). Understanding soil properties and processes helps in managing soil erosion, soil contamination, and the restoration of degraded lands. Soil science contributes to land-use planning and sustainable development also by studying soil characteristics, soil scientists can assess the suitability of different areas for specific land uses, such as agriculture, urban development, or conservation. This knowledge helps prevent soil degradation, preserve ecosystems, and optimize land management practices. Soils have a significant impact on water availability and quality. Soil science helps in understanding water movement through soils, infiltration rates, and water-holding capacity, which is crucial for efficient irrigation, groundwater recharge, and flood control. Proper soil management practices can help conserve water resources and prevent water pollution. Soils are home to a diverse range of organisms, including bacteria, fungi, insects, and earthworms (Totsche et al., 2010). Soil science explores the interactions between these organisms and the soil environment, contributing to the understanding of nutrient cycling, decomposition processes, and ecosystem functioning (Totsche et al., 2010). This knowledge aids in the conservation and restoration of biodiversity-rich soils. Soil science is essential for sustainable agriculture, environmental management, land-use planning, water conservation, biodiversity conservation, and construction projects. It provides valuable insights into soil processes and properties, helping us make informed decisions for the benefit of present and future generations. In recent timing the rise in urbanization and industrialization responsible for the number of toxic pollutants which are highly toxic for the living organisms. The excessive application of insecticides, pesticides and herbicides in the agronomy sector generates the pollutant which mainly include heavy metals such as chromium, antimony and mercury (Prabagar et al., 2021). Industrial effluents and waste discharge also contain heavy metals, toxic chemicals and synthetic dyes (Methneni et al., 2021). These untreated pollutants from industries are disposed into the aquatic water resources such as river and canals, by this the aquatic ecosystem get disturbed and vanished (Siric et al., 2022). These toxic pollutant alters the central nervous system, kidney dysfunction, cardiovascular diseases, hormonal imbalance ,Cancer, Skeletal disorders, malfunctioning of immune system and reproductive system (Fashola et al., 2020). Accidentally when the toxic pollutant or the heavy metals enter into the aquatic and terrestrial ecosystem, it leads to death of living organisms and the amount of these toxic pollutant bio-magnified from one trophic level to the next level. There are physical and chemical methods which are too expensive have been used from the past years, but these methods need high skills and special equipment for using practically which is the their main drawback(Mahmood et al., 2021). So there is a need for better alternative which is cheap, eco-friendly and efficient for the removal of these toxic pollutant(Sonune, 2021).

II. ROLE OF SOIL MICROBES IN MAINTAINING SOIL PROFILE

Bioremediation is a biological remediation process for pollutant treatment, it is most sustainable, affordable and efficient technique(Patel A.K.et al., 2022). Soil microbes are fundamental to the functioning and regulation of soil ecosystems. Their activities drive nutrient cycling, organic matter decomposition, soil structure formation, disease suppression, nitrogen fixation, and pollutant degradation. Understanding and managing microbial communities in soils are crucial for maintaining soil health, fertility, and sustainable land management practices.Microbes, including bacteria, fungi, Archaeabacteria, and other microorganisms, are vital components of soil ecosystems. They play crucial roles in regulating soil health, nutrient cycling, organic matter decomposition, and overall ecosystem functioning. Microbes are key players in nutrient cycling processes. They decompose organic matter, such as dead plant and animal material, into simpler compounds, releasing nutrients like nitrogen, phosphorus, and sulfur back into the soil. Microbes also facilitate the conversion of complex organic compounds into forms that plants can absorb and utilize,this shows that nutrient cycling is essential for maintaining soil fertility and supporting plant growth. Microbes are responsible for breaking down complex organic matter, such as plant residues and animal waste, into simpler compounds through the process of decomposition. This decomposition releases energy and nutrients that support microbial growth and contribute to soil fertility. It also aids in the formation of humus, a stable form of organic matter that improves soil structure and nutrient-holding capacity. Microbes, particularly fungi and bacteria, contribute to soil aggregation and formation of soil structure. They produce sticky substances like glues and Polysaccharides that bind soil particles together, creating aggregates. These aggregates improve soil porosity, water infiltration, and root penetration, leading to better aeration, water drainage, and nutrient availability. Certain microbes in the soil, known as biocontrol agents, can suppress plant diseases by inhibiting the growth or activity of plant pathogens(Pathak et al., 2022). They can compete with pathogens for resources, produce antimicrobial compounds, or stimulate the plant's defense mechanisms. This biological control of plant diseases reduces the reliance on synthetic pesticides and promotes sustainable agriculture. Some soil bacteria, called nitrogen-fixing bacteria, have the ability to convert atmospheric nitrogen into a plant-usable form called ammonium. These bacteria form symbiotic associations with leguminous plants (e.g., soybeans, clover) or exist freely in the soil. By fixing atmospheric nitrogen, these microbes contribute to the nitrogen supply in soils, benefiting both the associated plants and the overall ecosystem.Microbes can detoxify or degrade various pollutants and contaminants in the soil, including pesticides, petroleum hydrocarbons, and heavy metals. They possess enzymatic capabilities that enable them to break down or transform harmful substances into less toxic forms and microbial degradation processes are essential for soil remediation and the restoration of contaminated sites(Kumar G et al., 2022). Soil microbes are ubiquitous in nature and they absorb the toxic pollutant as sole source of carbon for production of ATP (Kour et al., 2022).These microbes have the ability to survive and flourish in adverse condition such as saline and marshy area(Perera and Hemamali, 2022).

Table 1: Different Bacterial Species Used in Bio-Remediation

Bacterial species	Pollutant Bio Remediate	References
Bacillus licheniformis JUG GS2 (MK106145) and Bacillus sonorensis	Naphthalene	(Rabani et al., 2022)
P. aeruginosa and Aeromonas sp.	Chromium, uranium, nickel and copper	(Gaur et al., 2022)
K. oxytoca, B. firmus, B. macerans, and Staphylococcus aureus	Vat dyes	(Sangkharak et al., 2022)
Saccharomyces cerevisiae and Cunninghamella elegans Heavy metals and mercury (Duc et al., 2021)	Heavy metals and mercury	(Duc et al.,2021)
Bacillus licheniformis	Dyes	(Mousavi et al., 2021)
Bacillus subtilis	Phenol	(Gaur et al., 2018)
Pseudomonas aeruginosa	Crude oil	(Mukjang et al., 2022)
Microbacterium sp., Micrococcus sp., Bacillus sp., and Shigella sp.	Uranium	Bhakat et al., 2019
E.coli	chromium	(Mohamed et al., 2020)
Bacillus sp. and Staphylococcus sp.	Endosulphans	Liu et al., 2018
Ralstonia sp., Microbacterium sp., Pseudomonas sp. and Acinetobacter sp.,	Aromatic hydrocarbon	Basu et al., 2018
Chlorella sp. and Spirulina sp.	Lead, nickel and dichromate	(Geetha et al., 2021)

III. MECHANISMS OF MICROBIAL BIOREMEDIATION

Microbes may eliminate contaminants from the environment through a variety of processes and these processes are classified into two basic categories: immobilisation and mobilisation (Verma and Kuila, 2019). Enzymatic oxidation is the process of converting hazardous substances from a higher to a lower oxidation state, in which heavy metals lose an electron and become less dangerous. This method makes use of an enzyme (oxidoreductase) produced by the bacteria involved. This approach is quite successful at removing dyes, phenols, and other contaminants that are not easily destroyed by bacteria(Unuofin et al., 2019).The oxidative enzymes generate radicals that may be broken down into distinct fractions, finally creating high-molecular-weight molecules (Unuofin et al., 2019). Laccase is an oxidoreductase enzyme that catalyses the oxidation of aromatic amines (Gangola et al., 2018). Other examples are phenols and polyphenols, which cause molecular oxygen to be reduced to water (Kushwaha et al., 2022; Sahay, 2021). Laccase formation has been observed in Pycnoporus sp. and Leptosphaerulina sp. to breakdown heavy metals(Tian et al., 2020).

IV. BIOAUGMENTATION

In a procedure known as bioaugmentation, microorganisms are specifically brought to contaminated places to feed on hazardous contaminants. It is a very effective, quick, and cost-efficient bioremediation approach (Mahmoud, 2021). External microorganisms are introduced into contaminated areas to supplement the native bacteria. In other circumstances, it may entail isolating and genetically modifying bacteria from the location of contamination before returning them to the same place for restoration, Because the organisms may not be naturally capable of decomposing the pollutant present at a place, genetic modification of resident microorganisms of contaminated areas is carried out, and thus they are transformed to boost their capabilities.In certain circumstances, non-resident microorganisms are introduced into contaminated locations to increase pollutant breakdown. The success of these new strains is determined by several variables, including their capacity to compete with native microorganisms and adapt to the new environment(Babalola et al., 2019).

V. ROLE AND TYPES OF BIOREMEDIATION

In the soil, there is a vast array of small microbes, and when xenobiotic compounds (foreign chemicals) accumulate in their habitat, it disrupts their suitable environment. However, these microbes have the ability to break down and transform these harmful xenobiotic compounds into less harmful forms using specific enzymes and metabolic pathways(Arora., 2020). They can even use these compounds as a source of carbon to produce energy for themselves. This process, known as biodegradation, is an environmentally safe way for microorganisms to manage xenobiotic substances.Two primary techniques used by microorganisms for breaking down xenobiotic compounds are aerobic biodegradation and anaerobic biodegradation. In aerobic biodegradation, the harmful compounds react with oxygen, with the end products being carbon dioxide and water, along with some leftover residue. This process requires a constant supply of oxygen to prevent bio-fouling in subsurface remedial treatments. Alkanes, which have long carbon chains and straight forms, are expected to be more easily broken down aerobically(Huang et al., 2017). In contrast, anaerobic biodegradation occurs in environments without oxygen, such as certain types of wastes, sediments, or waterlogged soils. Anaerobic bacteria can successfully remove xenobiotic compounds, converting them into carbon dioxide, methane, and water, along with leftover residue. Certain bacteria like Actinomycetes, Bifidobacterium, Clostridium, Propionibacterium, and Peptostreptococcus are commonly found in sewage treatment and wastewater treatment plants, and they play a significant role in anaerobic biodegradation(Morya et al., 2020).

Anaerobic sulfate-reducing bacteria and methanogenic bacteria are particularly useful for studying xenobiotic degradation. Biogas, primarily composed of methane, is a byproduct of the anaerobic digestion process, and it can be harnessed as a renewable energy source during the degradation of certain compounds(Xu et al., 2019).

Various bacteria are involved in xenobiotic bioremediation, including Acidovorax, Bordetella, Bacillus, Micrococus, Rhodococcus, Flavibacterium, Pseudomonas, Sphingomonas, Aeromonas, Alcaligenes, Variovora, and Veillonella alkalescens, among others. Additionally, bacteria like D. acetonicum, D. oleovorans, Desulfitobacterium dehalogenans, Desulfovibrio, Desulfuromonas michiganensis, and G. metallireducens contribute to the biodegradation of various xenobiotic compounds(Sharma et al., 2020). Bioremediation is the controlled biological breakdown of organic wastes in order to render them harmless or lower their concentrations below predetermined levels. It uses naturally occurring bacteria, fungus, algae, and plants to degrade or detoxify chemicals that are harmful to human health or the environment. To reduce pollution, this method employs natural processes such as natural attenuation, biostimulation, and bioaugmentation.Chemical operations create hazardous wastes, which are then treated using physicochemical and biological procedures to meet environmental criteria established by the Environmental Protection Act of 1986. Compound biodegradation is frequently the product of many organisms working together. Bioremediation occurs when microorganisms are added to a polluted place to aid with degradation. Biopesticides such as Trichoderma, Phytopthora, and Bacillus thuringiensis are routinely employed to target specific pests while also contributing to bioremediation initiatives(Angello et al., 2016).

VI. FACTORS ON WHICH BIOREMEDIATION DEPENDS

The control and optimization of bioremediation processes form a complex system influenced by numerous factors. These factors encompass the presence of a microbial population capable of degrading the pollutants, environmental conditions such as soil type, temperature, pH, the availability of oxygen or other electron acceptors, and nutrient availability(Luo et al., 2015).Microorganisms display remarkable adaptability, thriving in diverse environments, including sub-zero temperatures, extreme heat, desert conditions, aquatic settings, oxygen-rich environments, and anaerobic conditions. They can even grow in the presence of hazardous compounds or on various waste streams.

In Soil, the Rate of Biodegradation Depends on Four Key Variables

1. The availability of the pesticide or its metabolite to the microorganism
2. Physiologicalstatusofthemicroorganisms
3. Survivaland/orproliferationofpesticidedegradingmicroorganisms at contaminated site
4. Sustainable population of these microorganisms (Singh, 2014).

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VII. INCREASE DEGRADATION CAPABILITY THROUGH GENETIC ENGINEERING

Microorganisms display remarkable adaptability, thriving in diverse environments, including sub-zero temperatures, extreme heat, desert conditions, aquatic settings, oxygen-rich environments, and anaerobic conditions. They can even grow in the presence of hazardous compounds or on various waste streams. In soil, the rate of biodegradation depends on four key variables, namely, the availability of the pesticide or its metabolite to the microorganism. Another method of remediation includes inserting certain genes into indigenous bacteria to provide the capacity to degrade specific contaminants. This method is based on indigenous microbes conveying and absorbing genetic material(Singh., 2008).

There are two Approaches that may be taken

1. employing microbial cells to transport the gene via conjugation,
2. introducing naked genes into the soil and permitting absorption by transformation.

Pesticide and insecticide use has increased, resulting in contamination of our air, soil, and water, which eventually affects us through the food chain. To preserve a healthy environment and protect our well-being, it is critical to decompose these contaminants(Beek., 2001). Bioremediation is the most effective management strategy for dealing with polluted ecosystems and recovering contaminated soil and water**.** It is less harmful, has a lower environmental impact, targets specific organisms and pests, is effective in small quantities, and decomposes quickly(Vauramo et al, 2003). Moreover, it reduces exposures and helps avoid pollution problems. In the future, we may be able to apply genetic engineering to improve microorganisms' efficiency in decreasing the environmental load of harmful compounds(Mishra et al., 2021).

VIII. CONCLUSION

There is no doubt that pollutants and harmful have had a serious impact on soil fertility. Soils contaminated with these chemicals have garnered significant attention due to their adverse effects on human health and the natural ecosystem. Bioremediation offers tremendous potential for remediating soils affected by pesticides. The microorganisms present in the soil can effectively remove these harmful substances from the environment. Enzymatic degradation of pollutants using biopesticides is a crucial strategy for the removal and breakdown of persistent chemical substances. This enzymatic reaction-based bioremediation has shown high potential for addressing pesticide pollution. Therefore, bioremediation holds great promise as an effective approach to combat pollution in soils. This technology has repeatedly demonstrated its ability to degrade not only pesticides but also various inorganic compounds. It is time to embrace this eco-friendly technology for a better and safer future.

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