BIOREMEDIATION OF PESTICIDES

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Abstract

Pesticides, while essential for modern agriculture, pose significant environmental and health risks due to their persistence and toxicity. Bioremediation, a process that utilizes microorganisms to degrade and detoxify pollutants, offers a sustainable and eco-friendly solution to pesticide contamination. This study explores the classification of pesticides along with environmental issues caused by them. It also includes mechanisms and efficacy of various bioremediation techniques, including composting, bio-sparging, bioventing, bio-stimulation, etc. By examining various research papers and recent advancements, we highlight the potential of bioremediation to mitigate pesticide pollution in soil ecosystems.

KEY WORDS: Pesticides, Bioremediation, Environmental pollution, Toxicity, Soil health.

Introduction

The rapid increase in human population has led to enhanced crop production, due to which the use of wide variety of pesticides came into action. Following the fast utilization of pesticides, the amount of environmental pollution, especially soil pollution increased enormously.Several factors such as the pH, temperature, number, type of soil microorganisms play an important role in soil contamination process.To answer this problem, a lot of methods came up to eradicate or at least reduce the effects of pesticides in soil. One such accessible method is bioremediation; One of the ideal eco-friendly solutions for soil pollution reduction. Bioremediation is a kind of treatment that uses microorganisms that are capable of degrading various pesticides or hazardous chemicals into lesser or non-toxic compounds. In recent years, there has been a gradual increase in the studies of biodegradation and bioremediation of chemical pesticide contaminated soils.

Objectives

This is basically a review-based paper through which we want-

i. To enlighten upon the facts and issues related with current bioremediation techniques for removing pesticides.

ii. To analyze the environmental benefits and potential risks associated with bioremediation processes.
iii. To identify the key microorganisms that play a crucial role in the degradation of different types of pesticides.
iv. To explore the advances and innovations in the field of bioremediation.

Methodology

It is basically meta research through consultation of different research papers and reviews (national and international). We have found out the pertinent issues related with this matter and tried to represent the same. [13]

Classification of Pesticides

Pesticide is an umbrella term for different classes of insecticides, fungicides, rodenticides, herbicides, garden chemicals and household disinfectants. Pesticides have been classified into groups using various classification methods. [1,2]

1. ON THE BASIS OF MODE OF ENTRY:
   Systemic pesticides, Non-systemic (Contact) pesticides, Stomach poisoning and stomach toxicants, Fumigants, Repellents.
2. ON THE BASIS OF TARGET PEST:
   Insecticides, Fungicides, Rodenticides, Algaecides, Nematicides, Acaricides, Larvicides, Aphicides, Molluscicides, Miticides, Ixodicides, Bactericides, Herbicides.
3. ON THE BASIS OF CHEMICAL TYPE:
   Organic (Organophosphorus, Organochlorine, Carbamates, Pyrethroids), Inorganic, Synthetic, Biological, Arsenic compounds, Mercury compounds, Copper compounds, Bipyridinium derivatives, Coumarin derivatives, Nitrophenol derivatives, Phenoxy acetic acid derivatives, Triazine derivatives, Organotin, Pyrazoles, Thiocarbamates.
4. ON THE BASIS OF TOXICITY LEVEL:
   Scale indicating toxic level (Extremely hazardous to Acute hazardous)
5. ON THE BASIS OF MODE OF ACTION:
   Physical poison, Protoplasmic poison, Respiratory poison, Nerve poison, Chitin Inhibition.

Pesticides and Environmental Health

Although pesticides play an important role in agriculture, it has a severe adverse impact on environment. The biodiversity of soil fauna gets affected due to high toxicity and high biological activity of pesticides. Apart from the target pest, a lot of non-target organisms such as earthworms, protozoa, nematodes suffer DNA damage and alteration in enzyme activity. Beneficial microbial communities also get reduced by pesticide application. Needless to mention that enormous use of pesticides greatly harms the soil quality and quantity and develops a stress condition for both plants and microbes [14]. The amount of essential nutrients in the soil gets degraded and it adversely affect plant health. The pesticide residues can retain in the environment in many different ways such as absorbing into the soil, retaining in the air or dissolving in the water, etc. The toxic compounds in the pesticides may contaminate the underground water by percolation or can reach any water bodies by surface runoff. In this process the tissues of aquatic animals can absorb the pesticide residue and can pass on to the next trophic levels. So, all these directly affect the natural ecosystem. [3]

Biological Techniques for Pesticide Removal

The most efficient, cost effective, environment friendly approach for pesticide removal is Bioremediation. It is a type of biodegradation process in which the microorganisms use the pesticides in the form of co-substrate along with other nutrients for their metabolic reactions which in turn eliminate the pesticide from the environment. The efficiency of bioremediation depends on soil characteristics along with environmental factors such as pH, water content, temperature and microbial diversity.

Phases involved in the degradation process: [4]

i. Transformation of pesticides into more water soluble and less toxic products with the help of oxidation, reduction and hydrolysis reactions.
ii. The products are then converted into higher water soluble and less toxic sugars and amino acids.
iii. The metabolites (sugars and amino acids) are then converted into less toxic secondary conjugates.

Types of Microbial Degradation of Pesticides: [5,6]

Bacterial degradation: Researchers have identified several bacterial strains that have the ability to degrade pesticides. In presence of suitable conditions such as optimum temperature, pH, water content, etc. the bacteria degrade the pesticide into certain metabolites. In some cases, these metabolites also cause some adverse effect to the soil. That is why researchers prefer to use bacterial consortium compared to isolated pure culture. In case of using bacterial consortium, the metabolite produced by one bacterium while degrading pesticide can be used by another bacteria, as substrate.

Fungal degradation: Fungi can be exploited for degrading pesticide as it has the capacity of producing many enzymes that can alter the soil properties. Many researchers prefer using fungi and bacteria together to enhance the degradation process. Since fungi converts pesticides into some more accessible form for bacteria.

Enzymatic degradation: The enzymes produced during the metabolic processes of microorganisms and plants sometimes result in catalyzing the biochemical reaction for degradation of pesticides. The enzymatic actions of microbial depolymerases, hydrolases and peroxidases play a crucial role in the chemical transformation of the pesticides.

Mineralization: Mineralization is a process in which the pesticides are degraded into compounds such as NH_3, H_2O, CO_2. Mainly photolysis and hydrolysis reactions take place for such degradation.

Co-metabolism: In the process of co-metabolism, the pesticide is broken down using an enzyme or cofactor produced by microbes while oxidizing or reducing other compounds for energy and carbon. Main enzymes involved in co-metabolic process are hydrolytic enzymes, transferases, oxidases and reductases.

Popular Bioremediation Techniques

COMPOSTING: Composting is a technique in which the contaminated soil is mixed with the non-hazardous organic substance to enhance the bacterial and fungal population that have the ability to degrade pesticides in soil through co-metabolic pathway. Biochar, a black carbon produced by thermal conversion of biomass is added to the contaminated soil to promote pesticide degradation. High porosity and large surface area of biochar results into high water holding capacity and improved aeration condition which in turn promote the

adsorption of pesticides. Landfarming and bio-pilesare the techniques in which composting is used. This composting approach is used only when the pesticide concentration is low. [7]

NATURAL ATTENUATION: It is a natural process in which the pesticide is degraded by the indigenous microorganisms present in that soil. Dilution, volatilization, biological degradation, radioactive decay converts the pesticide into organic matter and clay minerals in the soil. [8]

BIOSTIMULATION: It is a process in which nutrients like nitrogen, phosphorus, carbon and oxygen are added in soil to promote the growth of indigenous microorganisms. Throughout the process, the amount of nutrients provided must be kept under control.Enhanced or reduced quantity of stimulant could result in decline of microbial community and activity. So, the greater the microbes in number the faster is the process of degradation of pesticides. [9]

BIOAUGMENTATION: It is a process in which microbial consortia or specific single strain is inoculated into the soil. If the indigenous microbes present in that area are found to be efficient in metabolizing the pesticides, then more of the indigenous bacterial cultures are added to the soil along with nutritional supplements. Otherwise, exogenous microbes having advanced pathways to degrade pesticides are added to the soil. [10]

BIOVENTING: It is an in-situ remediation process in which the microbial activity is enhanced due to the introduction of air or oxygen flow. In case of bioventing, nutrients along with oxygen are supplied into the unsaturated zone of soil by constructing wells into contaminated soil. Here the ventilation provided is light and it is kept noted to provide the optimum amount of oxygen needed by the microbes for microbial activity and volatilization of contaminants is avoided.[11]

BIOSPARGING: In this technique, the biodegradation process of aerobic microbes is induced by injecting air in ground water to increase the oxygen concentration. Unlike bioventing, in bio-sparging the air is injected in the saturated zone. This causes the upward movement of volatile organic compounds towards the unsaturated zone that in turn facilitate biodegradation. [12]

Conclusion and Future Perspectives

In most of the countries, due to the growing population improving productivity is of high priority. Butmost of the agricultural land is contaminated with high doses of pesticides. Unfortunately, these toxic chemicals by some means or the other impact human health, along with the environment.

Soil bioremediation is an impactful pathway to remove the harmful chemicals and pesticides which is carried out only by exploiting specific or indigenous microorganisms. Researchers are focusing on bioremediation of pesticides because of its ability to mitigate potential risk posed on the environment without losing the production and productivity in agriculture.

However, health problems and soil contamination due to pesticides still remain to be a burning issue. Researchers are relying more on genetically modified microorganisms that can prove to be much quicker in action than the indigenous microorganisms to degrade the toxic pesticides. Hence further studies are conducted to identify new microorganisms with capabilities to degrade pesticides more efficiently.

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