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Pesticide Infestation in Soil: Current Trends and Environmentally Benign Mitigation Approach

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ABSTRACT

Chemical pesticides are often employed in agricultural fields in modern agriculture to boost crop output. These pesticides influence the activity and abundance of beneficial soil microbial communities, in addition to controlling insect pests. Chemical pesticides disrupt soil microbial activities, which may alter the soil's ability to raise a crop. This has led to detrimental effects on soil ecosystem. With unprecedented use of pesticides, challenges related to bio-accumulation and bio-magnification has increased manifolds, which has necessitated pesticide removal by bio-degradation pathways. Pesticide degradation is influenced by a number of variables, including soil moisture, temperature, pH, pesticide composition and concentration. Insect pests and weeds in crops are effectively controlled with pesticides. This review examines pesticide associated risks, the mechanism of microbial degradation of pesticides, the factors that affect the degradation of pesticidesand the new pesticides due to the substantial threat that pesticide residues pose to the environment and human health.

Key words: *Anthropogenic, Bio-accumulation, Bio-magnification, Bio-degradation, Microbial diversity, Pesticide*

Introduction

Study of soil contamination is significant to scientific community because of known potential eco-toxicological hazards, origin of which are to unprecedented anthropogenic activities (Al-Taai, 2021). Seemingly crucial, it has exerted a detrimental impact on both biotic and abiotic resources of ecosystem. One such class of xenobiotic compounds which tend to bio-accumulate and hence bio-magnify in environment, are recalcitrant pesticides meant for pest control followed by its elimination from soil ecosystem. Functionally, they act by exerting deleterious effect on pest population, which concomitantly enhances crop produce and quality. Unprecedented, unchecked and overuse use of these recalcitrant chemicals have led to *eco-catastrophe* leading to soil, water and to a lower level, air pollution manifesting toxicological effects in both abiotic and biotic resources through bio-geochemical cycles traversing across different trophic levels (Raffa and Chiampo, 2021). One such visible effect is an alteration in pH of soil, which not only affects cultivars but also to soil health at large Badran (1988).

In addition to altered soil pH, different agricultural soil pollutants include litter, weeds, stubble, vegetable residues, crop stems, tree leaves and unripened fruits. This multi- factorial approach contributes to house different types of plant pathogens. This problem needs to be uprooted by minimizing secondary contributors of soil pollution as mentioned above, which are primarily organic in nature Al-Taai (2021). Soil is inhabited by untapped microbes from simplest of prokaryotic to eukaryotes and higher helminthes. A radical shift in soil microflora has been observed attributed to overuse of chemical pesticides and fertilizers which has led to declined soil fertility. Specifically, referring to indigenous fungal isolates occupying soil as their major ecological niche is dependent on the volume of inorganic and organic materials present. The micro-flora is exceptionally useful in the improvement of soil fertility but excess application of fertilizers and altered range of pesticides arrests the soil porosity Sofo *et al.* (2012). With unchecked use of pesticides, a remainder in the soil contributes to *microbial toxicity* hence limiting the microbial population which affects the community dynamics at large. Human exposure could be a resultant of ingestion of pesticide-contaminated water and food, the inhalation of pesticide-contaminated air and directly from occupational, agricultural and household use, rendering it to be potential agricultural associated occupational hazard. Different portals of pesticide entry like dermal, oral, eye, and respiratory pathways have been reported Kim *et al.* (2017). The adverse response and reaction of pesticides depends on the electronic properties and the structure of the molecule, dosage, and exposure times (Heard *et al.*, 2017). The residual pesticide concentration present in the soil must be reduced and effective remediation techniques must be proposed to obliterate these xenobiotics.

Currently, remediation preferences for pesticides are based on the intrinsic characteristic of each process, addressing biological, physical and chemical processes. Fungi and bacteria adapted to xenobiotics have been explored for their efficiency to degrade pesticides. Even though, the process is primarily used for its efficiency, low cost but depends on numerous factors, such as soil moisture content, nutrient availability, pH, temperature and oxygen level. In the physical remediation, low cost adsorption materials are known to possess pesticide removal efficacy from waste water. For instance, activated carbon has demonstrated to be an excellent adsorbent with great capacity for chelating pesticides owing to its high surface area. However, the adsorption process is complicated and depends upon soil characteristics such as structure, surface chemistry, pH, etc. There are many advances in the application of processes by Electro-Fenton, with platinum and Boron-doped diamond anodes being the most effective for the degradation of pesticides in aqueous medium (Abbott *et al.,* 2014). A sustainable, cost-effective, rather well-organized method is bioremediation, which is an alternative to more expensive and toxic approaches, such as chemical and physical methods. In biodegradation, the elimination can be achieved by exploiting the microbial activity of microorganisms. The microorganisms, primarily bacteria (Doolotkeldieva *et al.,* 2018), fungi (Erguven, 2018) transform pesticides into less complex compounds, CO_2, water, oxides or mineral salts, which can be used as carbon, mineral and energy source by the process of bio-mineralization.

Sources of soil pollution

Soil pollution is build–up of chemicals, radioactive materials, toxic compounds and soil-borne pathogens in the soil to exceeding levels that can lead to plant adversities. Current economic trends are sug-

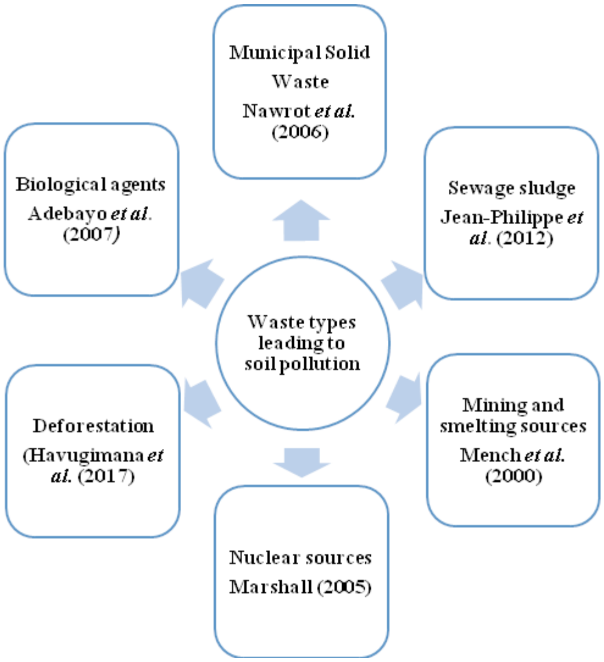


Fig. 1. Types of wastes responsible for soil pollution

gestive of need based *circular economy* credited to anthropogenic activities have significantly contributed to generation of different types of wastes and hence evolution of new xenobiotics moieties Tan (2009). Different types of wastes may be categorized as represented in Figure 1.

Role of pesticides in soil pollution

Though beneficial, pesticides contaminate soil and threaten soil health. Soil being the major reservoir of bio-geochemical cycles, bio-processes like mineralization, nitrification and phosphorous cycling rely much on soil's equilibrated state. The unchecked use of pesticides leads to most deleterious effect being exerted on enzymes indigenous to soil like dehydrogenase, cellulase, beta-galactosidase and urease. Bio-adsorption and bio-sorption of synthetic pesticides exhibits adverse effect on crop and cultivar.

On soil micro flora

Pesticides are known to exert eco-toxicological impact on soil in terms of quality deterioration (Arora and Sahni, 2016). Due to unprecedented use of pesticides, bioaccumulation and bio-magnification have been explicitly sought after. Native microbes and plants; as mono entities and in consortium mode have been explored for addressing pesticide contamination; owing to their natural attenuation property. Soil micro-flora; enrich soil's fertility by catalyzing degradation process. Actinomycetes are the chief modifiers and pesticide degraders (Diez, 2010). Soils contaminated by pesticides possess a wide array of properties like degradative, carriage and adsorption/desorption processes attributed to type of chemical moieties present in indigenous structure of pesticides Laabs *et al.* (2007). Persistent presence of pesticides in soil exerts detrimental impact on microbial diversity but increases functional diversity and community dynamics Wang *et al.* (2006). They also play a crucial role in out-competing other microbial counterparts (Chen and Edwards, 2001). Some organic contaminants (carbon-based compounds) can undergo chemical transformation to yield secondary intermediates leading into more toxic forms. An impact analysis of contaminants persistent and factors they depend upon are highlighted as follows:

On soil enzymatic activity

The activity of soil enzymes is largely dependent on physico-chemical properties of soil and numerous environmental factors, such as acid rain, heavy metals, pesticides and other industrial chemicals (Burns, 1982). Negative impact of pesticides on soil enzymes like hydrolases, oxido-reductase and dehydrogenase activities have been widely reported.

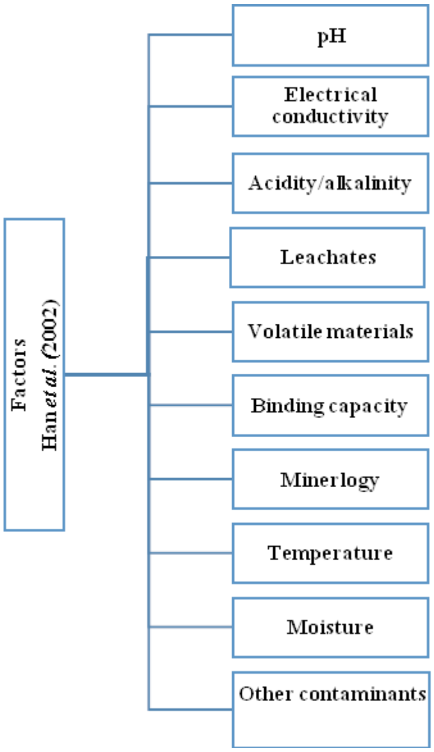


Fig. 2. Effect of pesticides on soil micro-flora

Impact on plants

Pesticides are aimed at pest control by two methods; either by static or cidal approach, limited information is available about the acute biological effects of these chemicals on their target organisms. Potential risks are always associated with excessive usage of pesticides. Benefits sought are equilibrated by an increased risk of phyto-toxicity, attributed to higher concentrations of pesticides applied to soil ecosystem. Antagonistic action of pesticides is represented in Figure 4.

Multi-factorial approach leads to toxicity such as type of pesticides, rate of application, spraying technique, climate conditions, micro-flora, humidity and physic-chemical properties of soil such as moisture, temperature, pH, texture and microbial activity Donald (2004). Physiologically, pesticide application causes *oxidative stress to plants* as a result of the generation of Reactive Oxygen Species (ROS) (Shahzad *et al*., 2018) which result in deterioration of chloro-

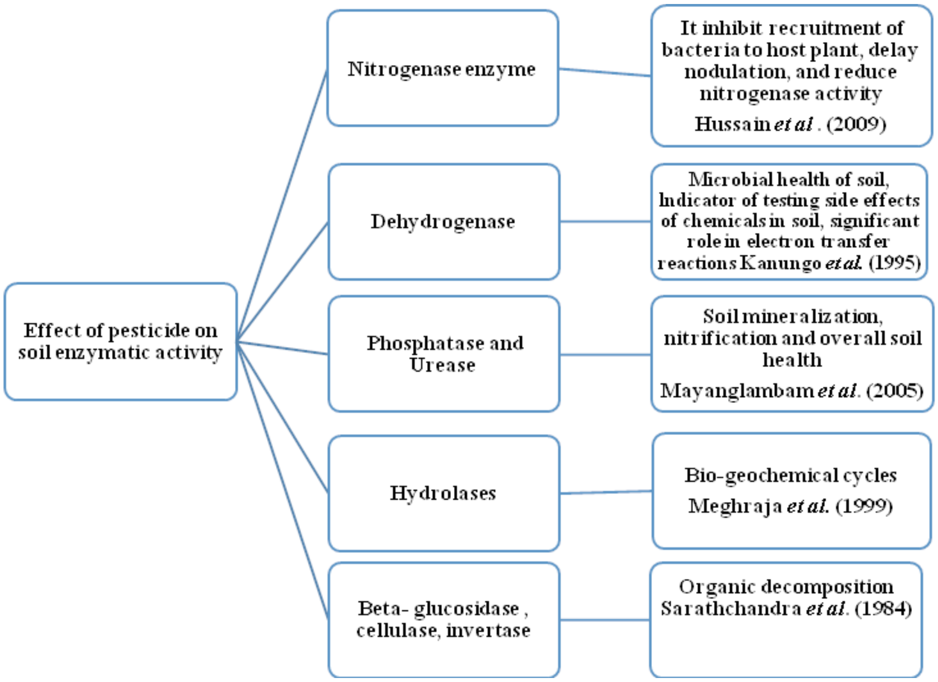


Fig. 3. Pesticides effectiveness on soil enzyme

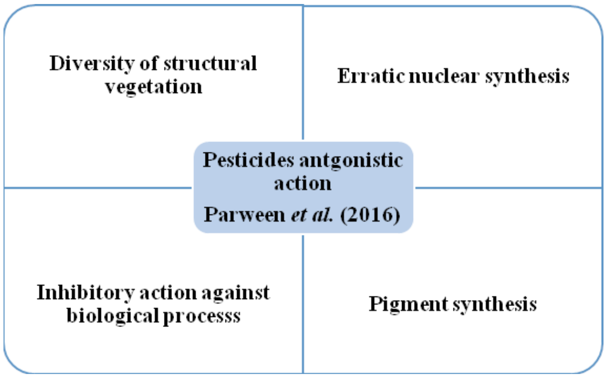


Fig. 4. Antagonistic action of pesticide on plant

phyll pigments and proteins leading to decline in photosynthetic efficacy (Sharma, 2014). Oxidative stress and anti-oxidative defense system involves enzymatic and non-enzymatic antioxidants (Xia *et al.*, 2006).

Path of contaminants from soils to human intake

Route of transmission of contaminated soil is depicted in Fig. 5.

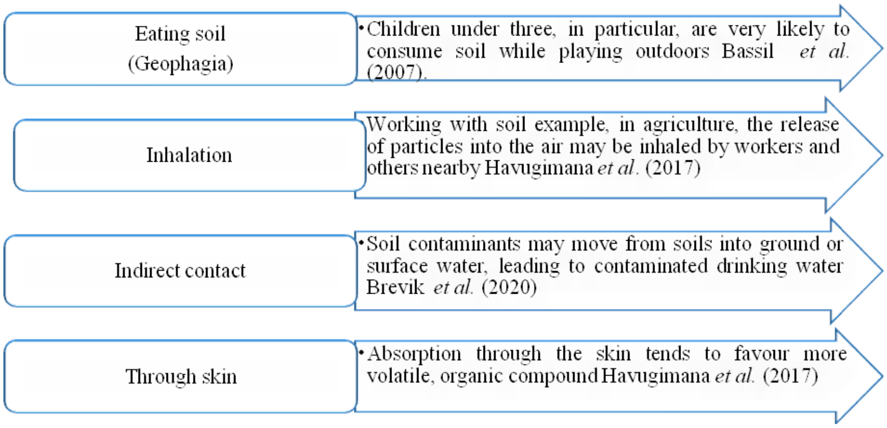
Strategies to overcome pesticide pollution in current scenario

Several effective methods can be employed to cope with the eco-toxicity caused by chemically derived pesticides. Until recently, a multitude of methods have been employed for safe, economical and efficient elimination of synthetic pesticides. The existing technologies rely on physical modes like adsorption and percolator filters; chemical treatments such as the advanced oxidation utilizing strong transient species (OH^-). The high temperature incineration is the current choice of treatment utilizing packaging of pesticides in places where they were abandoned followed by their transportation to a region having specific disposal facilities. The estimated cost of these operations by Food and Agriculture Organization (FAO), reportedly varies is between 3,000 and 4,000 USD/ton Ortiz-Hernández *et al.* (2011).

Another technique is based on photo-degradation of pesticides (Torres-Duarte *et al.*, 2009). All of these conventional physicochemical approaches have many drawbacks like their non-competitiveness and cost effectiveness with a resultant byproduct being more toxic than the parent pesticide compound, secondary amines in particular. To remove pesticide from contaminated environment, following measures are used as depicted in figure 6 Singh and Thakur (2006).

Thermal desorption (at low temperature)

The *ex situ* clean up technology frequently used to



- Children under three, in particular, are very likely to consume soil while playing outdoors Bassil *et al.* (2007).

Working with soil example, in agriculture, the release of particles into the air may be inhaled by workers and others nearby Havugimana *et al.* (2017)

- Soil contaminants may move from soils into ground or surface water, leading to contaminated drinking water Brevik *et al.* (2020)
- Absorption through the skin tends to favour more volatile, organic compound Havugimana *et al.* (2017)

Fig. 5. Effect of pesticides on human health

decontaminate pesticide polluted site is thermal desorption at low temperature which requires special handling and is cost-intensive. The process involves heating of media between 300 and 1000°F, which results in volatilization, but not organic compound degradation. Resultant organic compounds in the contaminated gas stream are then treated by either passing through a burner which results into complete condensation of contaminants. This process converts gas into a liquid phase for further absorption on carbon beds.

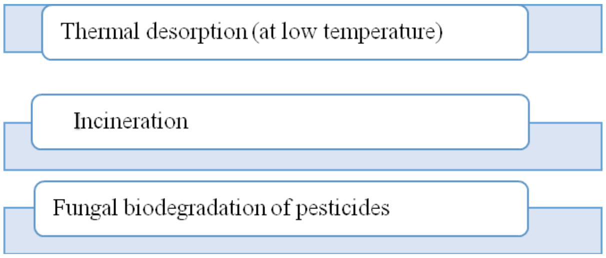


Fig. 6. Pesticide removal approaches

Incineration

The soil, sludge or sediments with organic contaminants are best been removed by an incinerator. It is essentially an oxidation process which involves heating of the contaminated media at temperature between 1,000 and 1,800°F that results in partial oxidation and the volatilization of the organics. This is followed by complete destruction of organics which operates at temperatures between 1,600 and 2,200°F. The resulting ash can then is disposed of in a landfill, after deeming it fit for landfills or composting.

Microbial approach to remove pesticide from soil

Bioremediation is an innovative, cost effective technology that is frequently being used for the clean-up of polluted sites. It is a procedure by which organic wastes are biologically reduced to a harmless state under controlled circumstances. Several indigenous microbes have been employed to break down or mitigate chemical pollutants that are eco-toxic and pose health adversities Murali and Mehar (2014). Bio-fungicide, such as *Trichoderma*, bioherbicides such as *Phytopthora* and bio-insecticides, such as *Bacillus thuringiensis*, are the most frequently utilized bio-pesticides that are pathogenic for the pest of interest. There are three categories of factors that have an impact on how microorganisms function:-

(1) Physicochemical aspects of the environment, or abiotic factors.

(2) Biological aspects of the environment or biotic factors.

(3) Climatic circumstances, Redox potential (Eh), pH, ionic strength, solubility, the presence or absence of electron acceptors and donors, temperature and the age of organo-metallic ions are only a few examples of the characteristics that make up physicochemical variables.

In the first step of harmful metal removal by microorganisms, called bio-sorption, the pH of a solution affects its iso-electric point, which changes the net negative charge on the surface of the microbial cells. The ionic state of ligands, such as carboxyl residues, phosphoryl residues, S-H groups and amino acid groups, is also altered by this shift while soluble metal ions can only undergo enzymatic reduction, bioremediation procedures entail reducing metal ions to an insoluble form by microorganisms from a higher to a lower oxidation state (pH - dependent). Metals in higher oxidation states are typically soluble (Garbisu and Alkorta, 2003). Given the fact, hydrophobic or sparingly soluble substances last in the environment for a long time and are bio-unavailable, solubility is crucial to the breakdown of organo- chlorines (Pieper and Reineke, 2000). Although, biological components are not always visible, their significance is frequently understood when using a bioremediation technology. Bacterial chemotaxis is a beneficial characteristic of bacteria that aids in the breakdown of organic molecules that are resistant to destruction (Pandey and Jain, 2002). The efficient operation of ecosystems on earth depends on microorganisms and factors altering the metabolism, composition and abundance of microbial communities that leads to ecosystem disruption (Nweke *et al.,* 2007). The potential of soil microorganisms to mitigate pollutants may be adversely affected by the allopathogenic response of terrestrial plants towards microbial community (Chakraborty *et al*., 2012). Research based evidence of climate change on soil microbes suggests changes in the physicochemical properties of the microbial niche, which may alter microbial metabolic processes and thereby the bioremediation, there is no direct evidence of any likely impacts of climate change on the bioremediation process. Production of microbial extracellular enzymes is correlated with microbial activity and soil physicochemical characteristics, both of which are controlled by climatic factors (Sowerby *et al.,* 2004; Castro *et al.,* 2004 and Nie *et al.* 2013). The following four factors affect the rate of biodegradation in soil:-

The presence of pesticides in the environment
- The physiological state of the organisms
- The survival and growth of creatures that degrade pesticides at polluted sites
- The sustainability of population of these organisms

The Commonly used intrinsic techniques of bioremediation are highlighted in figure 7.

Among microorganisms, especially bacteria have been isolated exhibiting potential to degrade xenobiotic contaminants. These bacteria *Pseudomonas* sp., *Arthobacter* sp., *Ralstonia* sp. and *Rhodococcus* sp. (Park *et al.,* 2003), *Bacillus* sp., *Planococcus* sp. and *Acetobacter* sp. (Shakoori *et al*., 2000) and *Alcaligenes* sp. (Padmanabhan *et al*., 2003), have more potential for degrading pesticides. Indigenous bacterial iso-

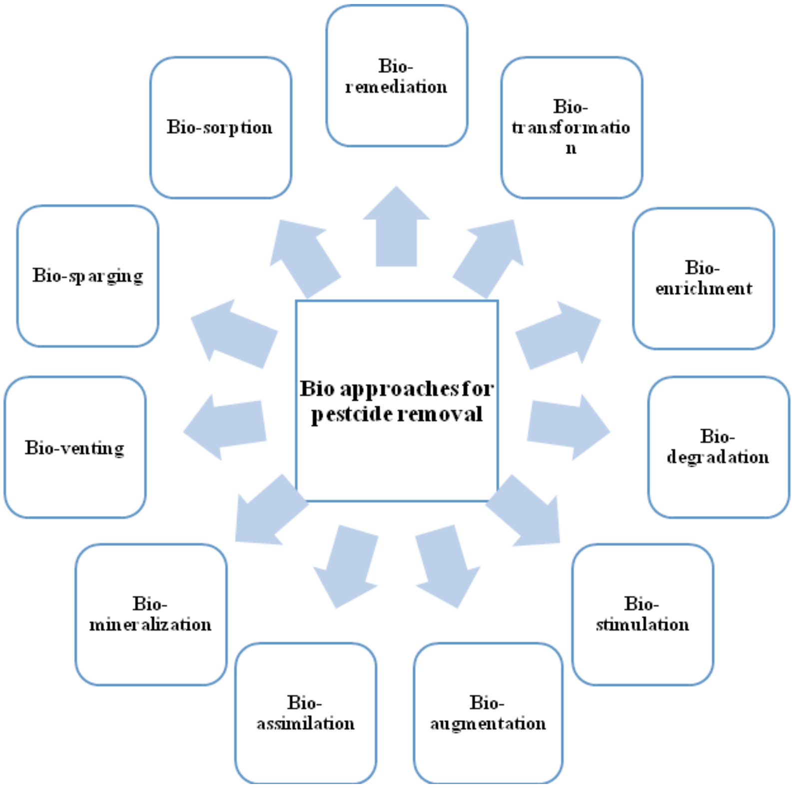


Fig. 7. Biological techniques for pesticides removal

lates have property of gratuitous metabolism (Sharma *et al.*, 2020) which exemplifies the property of contaminant degradation by bio-mineralization from the soil (Siddique *et al*., 2003). It is by virtue of constitutive and inducible enzymes, that microorganisms enzymatically attack the contaminants and transform them into less hazardous compounds for bioremediation to be successful. An efficient bioremediation can only be carried out in environment that supports microbial activity and growth this is why its application frequently entails changing environmental factors to speed up microbial growth and destruction (Sharma *et al.,* 2019).

Fungal biodegradation of Pesticides

Fungi counterparts as contrasted with prokaryotes, have been explored in recent past for their bioremediation of dairy waste water (Sharma *et al.,* 2022). Species of *Aspergillus* sp., *Allescheriella* sp., *Alternaria* sp., *Microsporum*sp., *Penicillium* sp., *Phlebia* sp., *Paecilomyces* sp., *Trichoderma* sp. etc. are known for their biodegradation properties with *Aspergillus* sp. being the most promiscuous (Mohapatra *et al.,* 2022). Wood degrading fungi such as *Phanerochaete* sp. and other related members have been extensively explored for pesticides degradation. Both constitutive and indigenous enzymes like peroxidase, utilizes contaminants as their substrates; have known to degrade pesticides, Poly Chlorinated Biphenyls (PCB) and Polycyclic Aromatic Hydrocarbons (PAH). Endosulfan degrading aerobic fungal strain *Aspergillus niger* has exemplified pesticide removal efficacy from soil (Bhalerao *et al*., 2007). Metabolic intermediates released after fungal activity such as Endosulfan diol, Endosulfan sulphate were identified by chromatographic procedures. In a study conducted by (Kamei *et al*., 2011), it was found that white rot fungus *Trameteshirsuta* successfully degraded Endosulfan and Endosulfansulphate. According to reports, strains like *Mortierella* sp. strain W8 and Cm1-45 degraded Endosulfan by 50 to 70 percent in 28 days at 25°C by first converting it into a diol and then an Endosulfan lactone, improving the fertility of agricultural land (Kataoka *et al*., 2010). *Fusarium verticillioides* metabolizes Lindane as a carbon and energy source under toxic environment in nitrogen and phosphorus limiting conditions. Different process parameters were found to have a significant effect on bio-degradation efficiency Urlacher *et al.*(2004).

Chlorpyrifos is rapidly degraded by fungus, which consumes it as its only source of energy and carbon and carries out bio-mineralization. The biodegradation of pesticides such as difenoconazole, terbuthylazine, and pendimethalin by fungi such as *Fusarium oxysporum, Lentinula edodes, Penicillium brevi compactum* and *Lecanicillium saksenae* in batch liquid culture have portrayed greater degrading capabilities (Shi *et al*., 2012). A report pertaining to biodegradation of pesticides in lower concentration in a combination is cited in literature. Briefly, the rates of degradation for DDT and Chlorpyrifos were 26.94% and 24.94%, respectively (Pieper and Rieneke, 2000). Organophosphonate herbicides are readily mineralized by phyto-pathogenic fungus (Shen *et al.,* 2010). *Trichoderma viride* and *Trichoderma harzianum* have a great capability for degrading pesticides like Pirimicarb. The degradation capacity rises with the addition of activated charcoal (Eapen *et al.*, 2007). *Sphingomonas yanoikuyae* is known to degrade Carbamate and Pyrethrin (Organo Phosphates) with great efficiency in challenging environments, was discovered by the enrichment culture approach (Cases and de Lorenzo(2005). The Carbofuran has been reportedly bio-transformed by a salt resistant Actinomycetes (Chougale *et al.,* 2007). *Streptomyces alanosinicus* is capable of degrading 95% Carbafuran in saline soils as the sole source of carbon Ningfeng *et al.* (2004). In addition to these, a number of fungal species, such as *Trametes* sp. and *Polyporus* sp. were capable of breaking down a wide range of compounds, including pesticides. *Aspergillus fumigates, Aspergillus sydowii, Aspergillus terreus, Aspergillus flavus, Fusarium oxysporum* and *Penicillium chrysogenum* have also been reported for their pesticide degradation efficacy (Hasan *et al*., 1999).

Conclusion

Globally, food insecurity is one of the major concerns. Agricultural industries and farmers largely depend on chemicals to meet raising food demand. In current scenario, farmers are using excessive pesticides and chemical fertilizers in unmanaged manner for higher yields. The unchecked application of these chemicals causes eco-toxic effects including, depleting soil health and fertility. Numerous studies on biodegradation of pollutants by microorganisms in the nature revealed that, these enzyme catalyze reactions have high bioremediation potential.

These biocatalysts, i.e. enzymes can beproduced on large scale by genetic engineering technology and expression of indigenous organisms, which are used in the agriculture field for removing pesticides from polluted areas. The indigenous microbial consortia contribute significantly for the mitigation of pesticidal residues from environment. These pesticides degrading microbial consortium may also serve as effective bio-fertilizers to substitute approximate 20–30 % chemical fertilizer. Thus, microbial degradation of pesticide can present a cost effective, eco-friendly and futuristic approach of diminution of contaminants from ecosystem.

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Conflict of Interest

Author's share none competing or conflicting interest

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