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How earthworm and fungi can save us from global food crisis and land degradation: A review

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Abstract

The human population is expected to be more than 9 billion by 2050. In order to feed this huge population, we would require about additional 60-70% food which is one of the major challenges ahead of humankind as well as to researchers. Although biotic stresses in soil such as microorganisms, insects, parasites, weeds are major reasons for reduced food production, abiotic stresses such as extreme temperature, soil salinity, natural disasters, pH imbalance are significantly affect the soil quality. There is not only degradation in soil quality but also a significant reduction in arable agricultural land in India affecting the productivity and nutrition values of the grains. Therefore, there is an urgent need to not only increase food production but also to maintain its nutritional quality. In addition, excess use of chemical fertilizers, increasing soil pollution and metal toxicity is becoming a serious threat and are responsible for reduced crop yield, crop failures and loss in agricultural economy worldwide. Moreover, the arable lands are not only shrinking due to industrialization, modernization and urbanization, ~50% of all arable land will be impacted by salinity by 2050. Indian continent is primarily agricultural driven and per capita land cover is decreasing day by day. On top of it, unregulated uses of chemical fertilizers are adding even more stress on the soil as well as produces greenhouse gases like N_2O. Therefore, management of resources for future needs is ought to attain the United Nations Sustainable Development Goals (SDG) which are related to zero hunger, no poverty, good health and well being. This review describes agronomical transformation through organic manure, biofertilizer, vermicomposting and mycoremediation. These techniques are essential for maintaining the soil quality as well as can act to approach sustainability in agriculture. The ecological engineering using earthworms for enhancing and restoring soil fertility is discussed in detail along with Mycoremediation of toxins and salt by utilizing macro and arbuscular mycorrhiza (AM) fungi.

Keywords
Soil, Abiotic and Biotic Stress, Earthworm, Bioremediation, Mycoremediation

Introduction

Soil is a fundamental resource of Earth's ecosystem which is connected with the atmosphere, hydro-sphere and lithosphere, serving as habitat for biota consisting of microfauna, mesofauna and macro-fauna (Bini, 2009) (See Fig. 1). The soil formation includes physical, chemical and biological decompo-sition of rocks, which is usually performed by fun-ction of five interacting factors of climate, parent material (rock), topography, organisms and time. (Osman, 2013). The biotic components such as organic matter, plant, micro-organisms have significant positive influence on soil properties compared to abiotic factors such as soil temperature, moisture and pH. (Schmidt, 2011). Soil acts as a natural sink and source for greenhouse gases (GHGs) such as CO_2 (Carbon dioxide), CH_4 (Methane), N_2O (Nitrous oxide) and primary and secondary nutrients depending upon different types of soil (Singh

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and Schulze, 2015). The rapid urbanization and industrialization around globe, especially in developing countries like China and India over the last few decades, has led to soil degradation and pollution, which is increasing even today at an alarming rate. These are affecting food production and quality, worsening the problems like hunger, malnutrition and poverty (Kumar et al., 2019; Zhao et al., 2015). Industrial and mining activities, poorly managed urban and industrial waste, fossil fuel extraction and processing, and unsustainable agricultural practices are identified as recent major sources of soil pollution (FAO and UNEP, 2021). According to UNEP report, ~149 million tons of synthetic nitrogen fertilizers were expected to be applied globally in the year 2021. Furthermore, the global annual production of industrial chemicals has doubled, resulting in an increased plastic use and more waste production. Due to population growth and urbanization, the world currently produces 2 billion tons of municipal solid waste per year and ~80-90% the generated waste is disposed of in landfills without proper management practices (Ahluwalia and Patel, 2018; Joshi and Ahmed, 2016). The generated waste is expected to rise at least 3.4 billion tons by 2050 (FAO and UNEP. 2021). The continuous dumping of waste, fall in arable agricultural land, urbanization, excessive use of chemical fertilizers, genetically modified crops, is alarming even for short term, i.e. 2050, much precautions and awareness regarding soil is crucial. The soil formation includes physical, chemical and biological decomposition of rocks, which is usually performed by function of five interacting factors of climate, parent material (rock), topography, organisms and time. The biotic components such as organic matter, plant, micro-organisms significantly influence soil properties compared to abiotic factors such as soil temperature, moisture and pH. On the other hand, decomposers such as bacteria, fungi, earthworm, millipedes, and insects don't let the waste pile up in soil and break them down into useful components such as organic matter and nutrients (Fig. 1).

Among several decomposers, Earthworms are simple, yet influential species, due to their morphology and physiology (e.g., elongated cylindrical body with tube within tube body plan) they easily transform the soil parameters by breaking down organic matter through their intestine and hence, are considered as "Keystone species" by soil ecologists (Kumar et al, 2020).

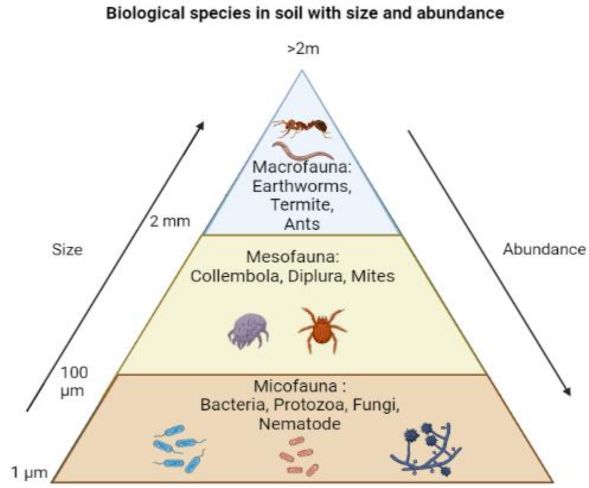

Figure 1. *Biological species participating in biological soil formation and quality improvement*

They provide assistance in enhancing the physio-chemical properties of soil, i.e., nutrients for growth of plants. Moreover, these unique features provide adaptation for underground burrowing and make easier for their movement in soil which effectively increases porosity, reduces soil bulk density forming macropores (M Bertrand et al, 2015). Thus, earthworms not only directly influence agricultural productivity by improving nutrients accessibility to the plants and restoring back the terrestrial carbon in soil but also helps percolation of water and soil aeration helping the growth of plant root system (Chan et al., 2002). The diversity, abundance and biomass of different earthworm species can provide vital information about various ecosystems including agro ecosystem, forests, grasslands etc.

Another decomposer i.e. Fungi which includes yeasts, rusts, smuts, mildews, molds, and mushrooms, are the most extensively dispersed creatures on the planet, having significant environmental and medicinal significance. Fungi are included in the kingdom Chromista and there are about 144,000 known species of organisms of Fungi kingdom. Some fungi live free in soil or water, while others have parasitic or symbiotic associations with plants or animals (Carris et al., 2012). Fungi are increasingly being used in bioremediation of heavy metals and other toxins in recent few years, called as Mycoremediation (Kulshrestha et al, 2014). Different types of fungi like white rot, marine, extremophilic, symbiotic etc. are involved in remediation, through saprophytic mode. For example, Bumpu et al. (1985) discovered and proposed the application of *Phanerochaete chrysosporium* in bioremediation studies.

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Fungi possess characteristics like ability to adapt and grow in certain environmental conditions along with changing temperature and pH, production of various extracellular lytic enzymes, high surface area to volume ratio, resistance to heavy metals, the presence of certain metal binding proteins etc., has made them a valuable biological tool to tackle soil pollution (Akhtar and Mannan, 2020; Singh et al., 2015). Enzymatic machinery involves monooxygenases, phenol oxidases, laccases, catalases, peroxidases and cytochrome. In addition, they can be used *in-situ* or in specially designed bioreactors for industrial waste management (Tekere et al., 2019).

Thus, there are relevant evidences to show the magnificent ecosystem services of earthworm and fungi towards the ecosystem which establish them as ecosystem engineers. Earthworms and fungi enhance soil fertility by decomposing the organic material into humic substances and the process is called humification. With declining condition of soil and decreasing food yield, finding safe and economic solutions and utilizing these biological engineers effectively, is of utmost importance. In this paper, the effects of earthworm and fungi on the soil ecosystem are explored further with their applications to in bioremediation.

Current Soil Status and health

Soil, the foundation of human life on earth, is continuously degrading and is at a huge risk, as a dispensable resource today. According to 2017 report of the UN, soil pollution, mining, farming and poor waste management has led to degradation of about one-third of world's soil and half of top soil has been lost in past 150 years, recently at the rate of 24 billion tons a year (IISD and UNEP report). Several reports have also projected that global production of industrial chemicals is expected to double every year due to poor management and disposal of these chemicals. They are expected to double again by 2030. A combined FAO and UN study suggests that the extent of soil pollution varies by region, for; farming is the major cause in Asia, Latin America and Eastern Europe; mining in sub-Saharan Africa; industrial pollution in Western Europe and North America; and urban pollution in North Africa.

Almost 30% of India's land is under desertification (ISRO, desertification and land degradation Atlas, 2021). Water logging and salinization have degraded approximately 1.07 million hectares. According to the ISRO's national database on land degradation, 120.7 million hectares (mha) or 36.7 percent of India's total arable land is degraded. Our country's annual soil loss rate is around 15.35 tons per hectare, resulting in nutrient losses of 5.37 to 8.34 million tons. Nutrient poor soils cannot produce healthy food for all necessary nutrients leading to poor health and biomass imbalance. Currently soil and land degradation is affecting at least 40% of world's population that is 3.2 billion people are being affected (UNEP report- Towards a Pollution Free Planet, 2021) and by 2050 it expected to be affecting more than 60% of world population. The review focuses on in these following sections, we have discussed efforts from the International as well as National level across the globe. In addition, we have also discussed why these efforts have failed? Finally, we present different remediation techniques (e.g., the use of earthworm and fungi) and their functioning to reclaim the soil health.

Different remediation techniques

Vermiremediation. Vermiremediation is a remediation technique in which biodegradation of contaminants is assisted by Earthworm. While burrowing they orally ingest soil particles or absorbing dermally, the contaminants present in soil gets accumulated in the gut. The excreta are called as vermicompost, which is rich in nitrogen, water soluble aggregates and minerals and this process is known as vermicomposting. (Hobbelen et al., 2006; Šrut et al., 2019). These are used as ready to use fertilizers to replenish the degraded soil and improve its fertility and productivity as they perform the vital role of fragmentation of organic matter, soil aeration which increases the nutritional quality and quantity in turn improving soil fertility Food and soils travel through the mouth, pharynx,, oesophagus, gizzard, stomach, and finally goes into the intestine (Marichal et al., 2017). Earthworms creates burrows, cast and breaking. The drilosphere is a round of earthworm's sphere of influence in soil environment (Dixon and Tilston, 2010). It is also explained as a burrow lining, which is directly and indirectly modified by earthworm (Bouché and Al-Addan, 1997).

Earthworms being the detrivores, are the link between living and dead organic matter, by degrading them in simple form, i.e., humus, they contribute to soil ecology (Fig. 2). They bring changes to both physical and chemical properties. The physical characteristics include stabilized organic content, reduced bulk density, reduced porosity and aggregate stability, moisture content and water retention characteristics. Earthworms

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have been shown to slow down the binding of organic contaminants to soil, release previously bound contaminants for later degradation, and promote and disperse organic contaminants degrading microorganisms (Hickman and Reid, 2008).

Organic contaminants become inaccessible to biodegradation as time passes (Bamforth and Singleton, 2005; Reid et al., 2000; Semple et al., 2003; Wolters et al., 2003). The physiological activities of earthworms such as shedding of exoskeleton, excretion and fragmentation of micronutrients has the potential to release the residues that have been trapped in a beneficial way for soil fertility and structure (Gevao et al., 2000; Verma and Pillai, 1991). Earthworms can take up and accumulate metals at tissue level which reflects their detritivores lifestyle (Fig. 2).

These tissues are made up of chlorogocytes with organelles capable of sequestering high concentrations of certain metals in relatively insoluble states (Morgan, 2009) and also increases nutrient mineralization in soil. Therefore, the use of earthworms for restoration of degraded soil can have significant role in reviving ecology of the affected area. In addition, a study conducted by (Mostafaii et al., 2016)found that earthworms are sensitive to soil contamination detection and assessment. As a result, earthworms can be used to detect soil contamination as bio-indicators (Sadia et al., 2020). Since most earthworm species feed on soil and decaying plant remains, their metabolic ability includes microscale interactions itheir metabolic n their gut. As mentioned in Figure 3, Epigenic earthworms (*Lumbricus rubellus*) prefer the organic matter in the soil, while Endogenic (*A. caliginosa*) and Aneic *(L. terrestris* and *A. longo*) earthworms prefer the composition of soil and organic matter in the soil (Doube et al., 1997). They can also eat fungi and bacteria that live in the soil (Schulze et al., 1993). There is a wide functional diversity of earthworm in various processes of ecosystem.

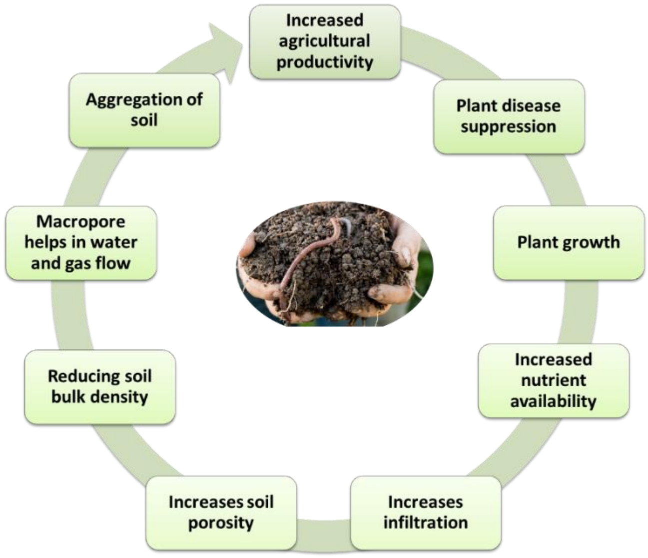

Figure 2. *Earthworms and their functions*

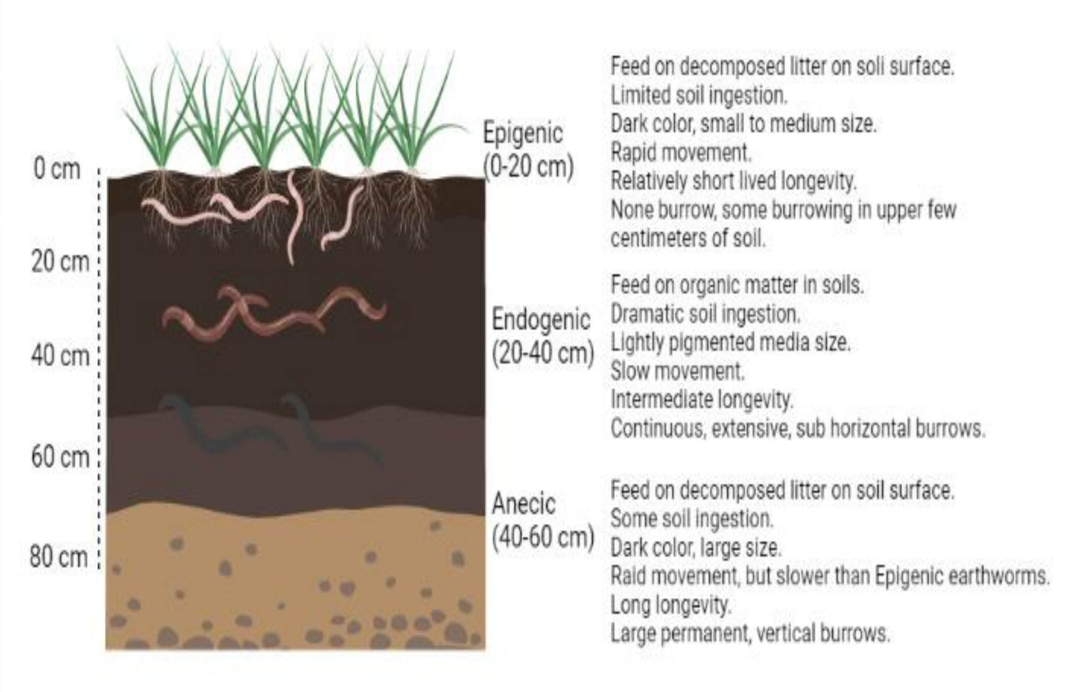

Figure 3. *Types and habitat of different types of Earthworms*

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As detrital surface area increases, the colonization and decay also enhance. Decomposition of organic matter in forests produces soluble organic acids, which have a significant influence on soil formation over time. Acids formed during litter decomposition on the top flow down into the soil, eliminating base cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K+) eroded from minerals with percolating water. The charge balance is maintained in the process by the buildup of H^{+} and the concentration of acid producing aluminum (Al). This acid leaching results in somewhat acidic (pH 6.5) to extremely acidic (pH 3.8) soils on the surface, which aids in the formation of specific profile characteristics associated with particular forests(LA Morris, 2004). Earthworms work as biochemical reactors, converting fragile plant compounds in to the microbial necro-mass in stable carbon pools without affecting bulk measures like total carbon content (Angst et al., 2019). Earthworms have been shown to deliver originally loose and compressed soil to a transitional mechanical state which is more beneficial for structural stability as well as root growth. Earthworms, especially endogenic geophagias earthworms, have been shown to enhance C and N mineralization in soil (Gopal Ramdas et al., 2017), most likely through a priming effect on soil organic matter decomposition rates (Bernard et al., 2007; Lavelle et al., 1987).

The priming effect is induced by earthworm gut transit, as evidenced by the fact that SOM mineralization rates seem to be lower in older casts than in newer ones.(Bernard et al., 2007; Pulleman et al., 2005) (Table 1).

In earthworms, high-activity enzymes such as polyphenol oxidase, catalase, protease, polysaccharides, glycosidase, phosphatase, and others may decompose humus, while humus is important for the adsorption and desorption of organic contaminants in soil (Du, 2018).

The villi absorb the digested materials, which are then passed into the bloodstream via capillaries. Almost 77 tons of dry weight of earthworm cast is produce per hectare per year in an Indian grassland site (Senapati and Dash, 1983). Earthworms have a direct (incorporation and redistribution of a variety of organic and inorganic materials, oxidation, hydration distribution, infiltration) or indirect (formation of microbial communities, propagule transportation, and pathogen inhibition) impact on soil processes (Buekers et al., 2007) (Table 2).

Table 1. *Study on vermiremediation of organic contamination in various substrates using different Earthworm species and their effectiveness*

Substrate	Organic contaminant	Earthworm species/ earthworm product	Duration (days)	Effectiveness of remediation	Study
Soil	Petroleum hydrocarbons (TPH)	E. fetida, L. terrestris	60	L. terrestris reduced TPH by 28.0%; E. fetida reduced TPH by 33.0%; E. fetida and L. terrestris jointly reduced TPH by 35.0%	(Almutairi, 2019)
Soil	Petroleum and diesel oil	E. fetida with and without activation biopreparation	154	E. fetida aided petroleum oil degradation (99%). Biopreparation had no significant effect. Remediation of diesel oil not successful	(Chachina et al., 2016)
Soil	Chlorpyrifos insecticide	Earthworm species not clearly indicated	3- 45	Earthworms aided degradation of up to 64.3 – 66.5%	(Ahmed et al., 2020)
Sewage sludge	PAHs	E. andrei	30	High removal of PAHs Earthworms accumulated PAHs	(Rorat et al., 2017)
Soil	Glyphosate-based herbicide (GBH)	Alma millsoni, Eudrilus eugeniae and Libyodrilus violaceu	56	Presence of earthworms decreased glyphosate residues in the contaminated soil	(Owagboriaye et al., 2020)

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Table 2: *Studies on vermiremediation for removal of metals in various substrates using different Earthworm species and their effectiveness*

Substrate	Metal contaminant	Earthworm/earthworm product	Duration	Effectivenessof remediation	Study
Landfill soil, wastewater	As, Hg in soil; Cr Ni, Pb, V in wastewater	E. fetida to remediate soil metals; Vermicompost used as adsorbent of wastewater metals	60	As in soil reduced by 42–72%; Hg in soil reduced by 7.5–30.02%	(Parra et al., 2010)
Urban waste soil	Cd, Cu , Mn, Pb, Zn	Eudrilus eugeniae, E. fetida, Perionyx excavatus	60	E. eugeniae reduced Pb by 32%; Zn by 37%; E. fetida reduced Pb by 45%; Zn by 44%; P. excavates reduced Pb by 51%; Zn by 56%	(Pattnaik & Reddy, 2011)
Biosolid	Cd, Cr, Cu, Pb, Zn	E.fetida from Iran; E. fetida from Iran Australia	60	Metal concentrations in the biosolid decreased with increasing vermicomposting time	(Shahmansouri, Pourmoghadas, Parvaresh, & Alidadi, 2005)
Residual soil in metal-polluted excavated soil	Cd, Cr, Pb, Fe	Earthworms in residence, E. fetida earthworms seeded culture, worm casts mixed with compost, photosynthetic microbial solution	700	Cr decreased from 192–194 mg kg^{-1} to 4.5–113.21 mg kg^{-1}; Pb decrease from 5,300 mg kg^{-1} to 1,550 mg kg^{-1}; No change in Cd, Fe levels	(Dabke, 2013)
Metal contaminated soil	As, Cr, Cu, Fe, Mn, Ni, Pb, Zn	L. rubellus	60	50% reduction in soil amended with mushroom compost	(Latifi, Musa, & Musa, 2020)

Earthworms processes and feeds on oligomeric molecules and return them to the soil as a plant growth hormone, humic substances. Earthworms and their gut microbes process nitrogen compounds to make nitrate to enrich the soil and produce N_2O, a greenhouse gas. Due to their involvement with soil particles and organic matter transfer, earthworms have an impact on nitrogen (N), phosphorus (P), pH, organic matter, and other factors. They profoundly affect the soil chemistry by enhancing nitrification process (secretion of labile carbon compounds to form nutrient rich casts. pH is increased as base cations from deep mineral layers are transferred to surface and produces carbon granules means it is helping in improving acidic soil.

The Impact of Earthworms on Salinity. *E.Fetida* thrives in Compost, which amends saline soil and boosts humic acid levels with nitrogen and phosphorus. Earthworms, according to Tao et al. (2009), could be used to improve saline soils. If enough food is provided for earthworms in saline soil, they will survive and population growth will be visible. Earconverted soil salinity to humic acidthworms, which is found in the form of Calcium humate and improves soil fertility and structure. An increase in N is directly related to GWC, not on the soil or the earthworm, if GWC is present then, its converted with help of earthworms into available nitrogen. About 20-50% of total P in soil is bio-available, rest which are biologically unavailable are made bio-available by activities of earthworm. In addition, K availability is also enhanced by addition and decomposition of cow dung via these annelids . E. fetida can tolerate higher soil salinity than other earthworm species, but they don't go deeper than 20cm, so their contribution to improvement is limited. However the Maximum decrease in salt content was observed to be 9.9 kg of GWC/m^2 when applied in saline soil. This means abundant quantity of food is necessary for earthworms for amelioration (Zhang et al., 2015)..

Mycoremediation

Mycoremediation is a technique which utilizes fungi to eliminate toxic substances and remediate resources.

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Fungi mostly feeds on litter and decomposes them and as a result of changing environmental conditions, fungi can produce a wide range of enzymes and secondary metabolites. The substrate's nature and the fungal plasticity of the fungus can then be combined to transform contaminated soils and restore degraded areas (Kulshreshtha et al., 2014). Mycoremediation does not require any pre conditioning of contaminants and are effective for a wide range of pollutants. Fungi like yeasts and molds are referred to as micro-fungi, and mushrooms as macro-fungi. Fungal anatomy consists of mycelia and hypha. Hyphae (singular Hypha) are long branching, thread like filamentous structure. Group of mass of hyphae constitutes mycelia (singular Mycelium). Fungi uses mycelium to colonize the plant root system and soil. Nutrients from surroundings are also absorbed through mycelia (Singh et al., 2015). Certain Physio-chemical factors like temperature, pH, bioavailability of nutrients and relative humidity affect the process of Mycoremedia-. tion. It is observed that degradation process is higher at high temperature. It is evident from comparatively higher degradation of organic contaminants in tropical soils, than temperate soils (Zarea et al. 2013). Basic pH favors degradation of contaminants due to increased solubility (Bumpus et al., 1985). For effective Mycoremediation, relative humidity is kept above 60% (Meharg, 2001). Fungal life cycle, species, and soil chemistry are some other factors governing Mycoremediation.

Mycoremediating toxicity and salinity with macro and AM fungi. Mushrooms have the ability to accumulate a wide range of toxic metals, pollutants, chemicals through adopting efficient bioaccumulation of toxic chemicals under the process of bio-remediation, specifically referred as Mycoremediation, is generally done in three steps: Bio degradation, bio-conversion and biosorption, through rich network of Hyphae (Fig. 4).

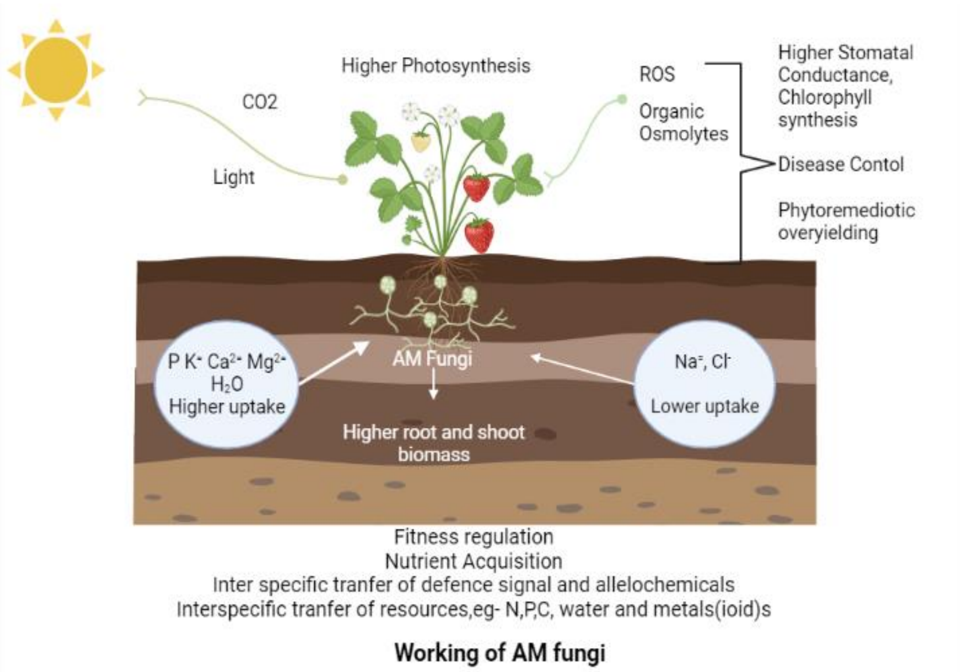

Figure 4
Working of AM Fungi

Mushrooms can grow and survive almost everywhere, from agriculturally rich land to ecologically, agriculturally, industrially and toxically meta-polluted land, even in stones. They are well known to produce proteins which are 2nd most easily digestible protein and free of cholesterol. The uptake of toxic chemicals, heavy metals, salinity (Giri et al., 2003) and other pollutants happens through physio-chemical interaction of metallic ions with cellular compounds of the biological species. Heavy metals and mineral oils contaminate the soil. Fungal species such as *Rhizopus, Paecilomyces, Alternaria, Mucor, Gliocadium, Aspergillus, Fusarium, Cladiosporum, Pleurotus*, and others use enzymes such as hydrolases, dehydrogenases, and membrane bound cytochrome P450 to degrade hydrocarbon contaminants and use them as a carbon and energy source

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Table 3. *List of fungi up taking heavy metals*

Serial Number	Heavy Metal	Name of Fungi	References
1	Al	Penicillium simplicissimum (iso 10, KP713758), Simplicillium chinense, Trichoderma asperellum,	(Butt et al., 2017), (Li et al., 2013), Chan et al., 2016)
2	As	Exophiala sideris, Psilocybe semilanceata, Trichoderma ghanens	(Horrigan and Stamets, 2006), (Dey et al., 2016), (Li et al., 2018)
3	Cd	Aspergillus aculeatus, Aspergillus flavus, Aspergillus foetidus, Aspergillus niger, Aspergillus terreus PD-17, Acremonium persicinum, Beauveria bassiana, Beauveria bassiana 4580, Candida albicans, Fusarimum solani, Humicola sp., Paecilomyces fumosoroseus, Penicillium simplicissimum, Penicillium sp.,Trichoderma asperellum, Trichoderma ghanense, Trichoderma harzianum, Trichoderma sp., Trichoderma tomentosum, Cantharellus cibarius, Fomitopsis meliae, Ganoderma aff. Steyaertanum, Phanerochaete chrysosporium, Pleurotus ostreatus, Alternaria sp., Rhizomucor pusillus, Rhizophagus irregularis, Rhizopus arrhizus UCP 402, Rhizopus microspores	(Xie et al., 2014), (Bazrafshan et al., 2014), (Chakraborty et al., 2014), (Cui et al., 2018), (Dey et al., 2016), (Mohammadian et al., 2017), (Kumar et al., 2019), (Dey et al., 2016), (Butt et al., 2017), (Oladipo et al., 2018), (Cecchi et al., 2017), (Bazrafshan et al., 2016), (Mohsenzadeh and Shahrokhi, 2014), (Drewnowska et al., 2017), (Kaewdoung et al., 2016), (Huang et al., 2017), (Freitas et al., 2015), (Tahir et al., 2017), (Mohsenzadeh and Shahrokhi, 2014)
4	Co	Cheatomium .sp, Neurospora sp, Saccharomyces cerevisiae	(Sani et al., 2017), (Desai et al., 2016), (Ruta et al., 2017), (Kumar and Dwivedi, 2021)
5	Cr	Aspergillus flavus,Aspergillus fumigates,Aspergillus niger,Aspergillus niger MSR4,Aspergillus oryzae,Aspergillus sp., Aspergillus terreus, Aspergillus terreus PD-17, Acremonium sp.,Beauveria bassiana, Beauveria bassiana 4580, Cyberlindnera jadinii M9, Fusarium oxysporium, Neurospora sp., Paecilomyces chysogenum, Paecilomyces fumosoroseus 4099, Penicillium griseofulvum MSR1, Penicillium simplicissimum, Penicillium simplicissimum (iso 10, KP713758), Penicillium sp., Simplicillium chinense, Trichoderma asperellum, Trichoderma asperellum PTN7, Trichoderma viride, Coriolopsis sp. (1c3 KM403574), Phanerochaete chrysosporium	(Panda et al., 2014), (Arshad and Aishatul, 2015), (Sepehr et al., 2014), (Pundir et al., 2018), (Sriharsha et al., 2017), (Dey et al., 2016), (Herath et al., 2014), (Gola et al., 2019), (Irazusta et al., 2018), Migahed et al., 2017), (Purchase, 2016), (Akpomie and Ejechi, 2016), (Chang et al., 2016), (Sakthivel et al., 2016), Noori et al., 2014), Xu et al., 2015).
6	Cu	Aspergillus flavus, Aspergillus niger, Aspergillus sp, Aspergillus terreus, Acremonium persicinum, Beauveria bassiana, Chaetomium globosum, Flammulina velutipes, Neurospora sp., Penicillium janthinillum (GXCR), Penicillium simplicissimum, Phialophora malorum, Phialophora mutabilis, Trichoderma ghanense, Trichoderma harzianum, Antrodia xantha Shiga-1F,Auricularia polytricha, Fomitopsis cf. Meliae, Fomitopsis meliae, Fomitopsis palustris TYP-0507, Ganoderma aff. Steyaertanum, Phanerochaete chrysosporium, Pleurotus eryngii, Pleurotus florida, Pleurotus ostreatus, Rhizopus microspores, Rhizopus oryzae	(Coreño-Alonso et al., 2014), (Pundir and Dastidar, 2016), (Abou-Taleb et al., 2017), Arshad and Aishatul, 2015), (Mohammadian et al., 2017), (Gola et al., 2019), (Tahir et al., 2017), (Oladipo et al., 2018), (Salvadori et al., 2014), (Cecchi et al., 2017), (Kaewdoung et al., 2016), (Hattori et al., 2015), (Zhang et al., 2020), (Packiyam et al., 2014), (Oladipo et al., 2018), (Li et al., 2018).
7	Hg	Auricularia polytricha, Pleurotus eryngii, Pleurotus ostreatus	(Cui et al., 2018), (Purchase, 2016)
8	Ni	Aspergillus niger, Aspergillus terreus PD-17, Beauveria bassiana, Beauveria bassiana 4580, Neurospora sp, Penicillium sp. Saccharomyces cerevisiae, Trichoderma harzianum, Phanerochaete chrysosporium, Alternaria sp.	(Pundir et al., 2018), (Netpae et al., 2015), (Dey et al., 2016), (Zhang et al., 2020), (Cecchi et al., 2017)
9	Pb	Aspergillus flavus, Aspergillus fumigatus PD-18, Aspergillus niger, Aspergillus niger A40, Aspergillus terreus, Aspergillus terreus PD-17, Acremonium persicinum, Beauveria bassiana 4580, Fusarium oxysporium, Fusarium oxysporum UF8, Neurospora sp, Paecilomyces javanicus, Penicillium chrysogenum, Penicillium janthinillum ,Penicillium simplicissimum, Penicillium simplicissimum, Simplicillium chinense, Trichoderma asperellum, Trichoderma ghanense, Trichoderma harzianum, Trichoderma logibrachiatum, Trichoderma viride, Coriolopsis sp., Fomitopsis cf. Meliae, Fomitopsis meliae, Ganoderma aff. Steyaertanum, Phanerochaete chrysosporium, Mucor indicus, Rhizomucor pusillus	(Dey et al., 2016), (Coreno-Alonso et al., 2014), (Sharma and Pathak, 2017), (Khadiga et al., 2017), (Migahed et al., 2017), (Cui et al., 2018), (Mohammadian et al., 2017), (Mohsenzadeh and Shahrokhi, 2014), (Devi et al., 2017), (Kaewdoung et al., 2016), (Huang et al., 2017).
10	V	Aspergillus niger	(Arshad and Aishatul, 2015), (Kumar and Dwivedi, 2021)
11	Zn	Aspergillus niger,Aspergillus sp., Aspergillus terreus, Acremonium persicinum, Beauveria bassiana, Cheatomium .sp, Neurospora sp., Penicillium chrysogenum, Penicillium simplicissimum, Trichoderma harzianum, Fomitopsis cf. Meliae, Ganoderma aff. Steyaertanum, Pleurotus eryngii, Pleurotus ostreatus, Rhizopus oryzae	(Arshad and Aishatul, 2015), (Sepehr et al., 2014), (Pundir and Dastida, 2015), (Dey et al., 2016), (Gola et al., 2019), (Mohammadian et al., 2017), (Li et al., 2018), (Borovaya et al., 2015), (Tahir et al., 2017)

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(Zhang et al., 2016; Ameen et al., 2016; Dawoodi et al., 2015). Incomplete combustion of organic materials produces Polycyclic Aromatic Hydrocarbons (PAHs) that bind to soil particles and remain absorbed.

Many fungal species, as mentioned above, degrade PAH using *ligninolytic*_enzymes and P450_*monooxygenase* (Aranda, 2016; Aydin et al., 2017) *Macrofungi* species like, *Russula delica, Plurotus tuberregium, Calocybe Indica, Stropharia rugosoannulata, Stropharia cubensis, Rugoso annulata, Pulveroboletus Amarellus, Panaeolus cyanesceus, Panaeolus cinctilus, Tricholoma lobayense, Lentinela edoclus, Psalliota campestris* have shown very high affinity to absorb, Cr, Cu, Cd, Zn, TCP(2,4,5- *trichlorophenol*), Pb, As, PAHs, organic and inorganic dyes, 2-4-dichloro-phenol, crude oil, malachite green, radioactive cellulosic based waste (Gorza et al., 2018; Yang et al., 2014). The highest dissipation reported is as: TCP at 96.24%, Cd, Cu, Pb, Zn, As dissipated at 135 mg/kg, 77.92 mg/kg, 25.95mg/kg, 142mg/kg, 1.6 mg/kg respectively of growth media. Mushrooms are able to bio convert barley, wheat, rice straws and stacks, and lignin of wood to maximum yield within 6 days. Enzymes are used in this biodegradation and biotransformation process to access cellulose and hemicellulose chains, thus degrading lignocellulosic material into sugar monomers for production of ethanol by fermentation process using yeast which can be used beneficially by industries.

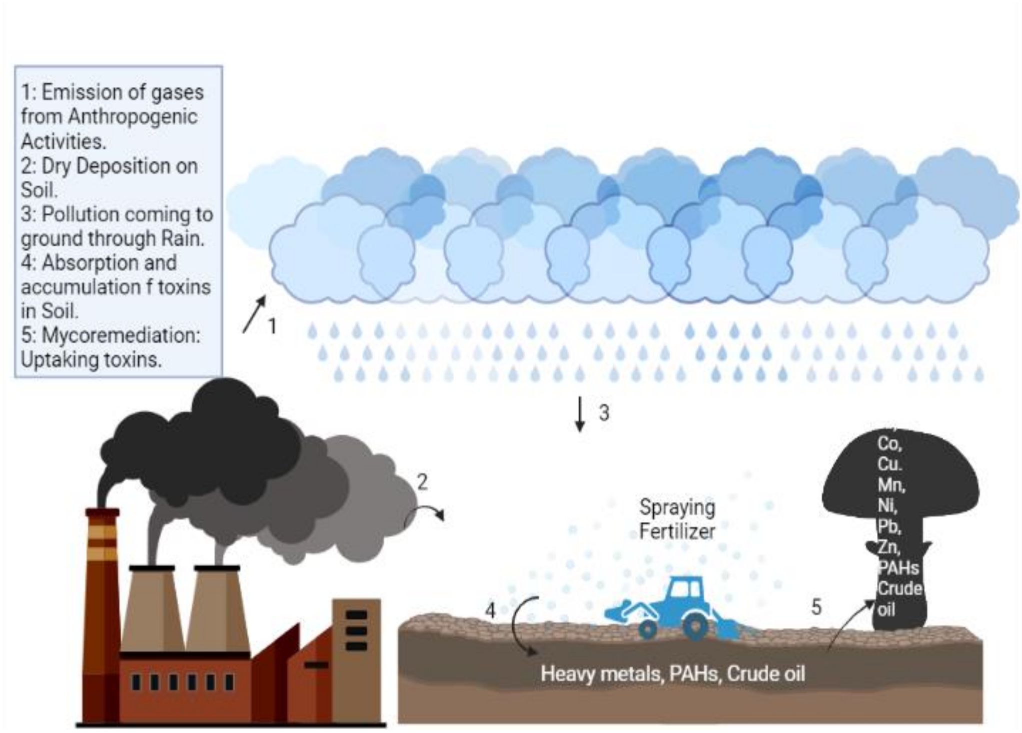

Figure 5
Process of soil pollution and remediation

(*Arbuscular mycorrhizal* (AM) fungi works symbiotically with plants and *mycoremediates* through *mycofiltration*, which confer the plant to increase tolerance to salinity, increases root phosphorus uptake, therefore enhancing plant growth and yield and have been reported to bio ameliorate salinized soil (Giri et al., 2003; Veiga et al., 2013) defines AM as "the mother of plant root endosymbiosis" in natural ecosystems. AM symbiosis is the most widespread plant strategies to cope with biotic and abiotic stresses. It improves water and nutrient acquisition, especially P, decreases Na^+ uptakes, favors K^+ and Mg^+ uptakes, increases the K^+/Na^+ and Mg^{2+}/Na^+ ratio in shoots, nutrient use efficient, photosynthesis, respiration and plant metabolism.(Baraza et al., 2016).

Conclusions

Some of the above-mentioned species of mushrooms are edible, some are not, but they have the enormous capability to totally bioremediate a land which is now called waste or barren land because of so called human advancement through industrial waste water, over ex-

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ploitation and excessive use of chemical fertilizer and pesticides. Though myco and vermi remediation is time consuming process compared to the pace expected in AI world, but this is the most economical and carbon negative way out, considering most of the population residing in third world countries. This will surely overcome the challenges of global food security, devastating salinization and increasing energy demands, by cultivating mushrooms and plants with high biomass low water uptake, low maintenance with very low or no fertilizer requirement for biomass generation and enriching the soil with Ecosystem engineers the Earthworms at the same time, so they keep on feeding the waste and improving soil quality, together. These processes should be maintained till the degraded soil regains back its fertility. In addition, when the soil gains back its fertility, it must not be laced again with pollution and chemicals, rather organic farming practices like, use of original seeds for plantation, compost and vermicompost for nutrition, cow dung, urine, neem oil, ash and lime mixture for pest control, should be used. Mushrooms and archaic yet neglected wild crops which are termed as Superfoods, such as *Diplazium esculentum*, *Fumaria indica*, *Taraxacum campylodes*, *Urtica dioica, Cannabis indica, Phyllanthus emblica*, *Punica granatum*, *Cordia dichotoma*, *Syzygium cumini*, *Ficus palmate, Moringa oleifera* should be welcomed in our eating habits along with change in eating habit and food culture.

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