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EFFECT OF PESTICIDES ON SOIL ECOSYSTEM SERVICES AND PROCESSES

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ABSTRACT

The livelihood of the entire population and the existence of farming communities is solely dependent on agriculture. Fertility of the soil is governed by its texture and diversified fauna present in the soil medium. Various agricultural inputs are applied with the eventual aim to achieve the highest productivity whereas hazardous effects on soil microorganisms are often ignored. Pesticides are noxious chemicals used to mitigate crop losses incurred by nematodes, insects, weeds, mites, and pathogens. Fungicides modify the fungi communities accountable for the nutrient recycling in the soil, especially copper-based fungicides which cause harmful effects on earthworms. The continuous use of herbicides indirectly reduces the associated arthropod communities. Insecticides cause toxic effects on most of the lower soil invertebrates and cause negative impact on their growth and development and alter the trophic structure in their habitats. Buildup of synthetic pesticides in the soil cause many sublethal effects on the existing natural fauna and affects their survival. However, pesticides help in diminishing the quantitative losses caused by pests and enhance the agricultural productivity, but consequently the cost of enhanced productivity is compensated by the Earth's ecosystems. This review provides insight into the effects of pesticides on the soil health.

Key words: Ecosystem services, communities, insects, nematodes, weeds, mites, pathogens, pesticides, insecticides, herbicides, fungicides, nematicides

Pesticides are used to safeguard the crops against various threatening pests, which include insects, nematodes, mites and rodent etc. In India, the losses due to pests stand for US$ 42.66 million in monetary terms (Sushil, 2016). Pesticides may be organic or inorganic compounds and categorized asper target pests. Pesticides may be an insecticide, herbicides, rodenticides, molluscicides, and nematicides etc. are the essential evil as they can manage the pest's problem rapidly in the field compared to all other available management techniques. But on the other hand, these pesticides are accountable for the weakening of the environment and human health; have a threat to essential fauna and flora existing in aquatic and terrestrial ecosystems. Any release of new pesticides goes through various developmental processes of risk analysis on essential micro-fauna and micro-flora of soil and water. Microbial densities and their activities determine the physical properties of soil (Abd-Alla and Omar, 1993), which possess an unavoidable threat from the pesticide residues in soil or in groundwater. The long-term persistence of pesticides residues impacts negative effects on the soil function and properties like rhizodeposition, soil organic carbon, pH, and moisture etc. The microbial populations or decomposers are responsible for the recycling of net primary production (Hussain et al., 2009) and participate in various soil biological processes (Cycon and Piotrowska-Seget, 2007). But microbial population stability is disturbed by erratic and excess uses of pesticides. The arbuscular mycorrhiza fungi are responsible for the better growth and development of plants but reported to affected by pesticide's toxicity, which suppresses the growth of mycelia (Sreenivasa and Bagyaraj, 1989) and systemic pesticides damages AM fungi more than the non-systemic fungi (Menge, 1982). It has been reported that nodulation in legume crops by Rhizobium and Bradyrhizobium bacteria suppressed by the over uses of pesticides (Abd-Alla et al., 2000).

Overview of pesticide use in agriculture in India

In India, the insecticide and fungicide market is dominant over herbicides and rodenticides (Fig. 1). The share of insecticides reduced from 70% in 2003-04 to 39% in 2016-17. Indian traders generally procure technical ingredients of the pesticides formulations, which is safeguarded by patents and the readymade formulations are exported to many countries via established trade channels. Average consumption of pesticide in India is 0.6 kg/ ha asper CIB&RC, which

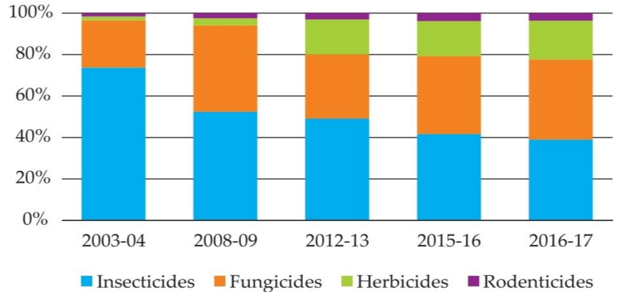

Fig. 1. Usages of pesticides in agriculture (Subash et al., 2017)

is very low in comparison to developed countries. In the category of pesticides, insecticides shares are highest among all pesticides. The overall uses of pesticides reported highest in Maharashtra, followed by Madhya Pradesh, Punjab and Haryana. Consumption of pesticides is highest in Punjab which is reported to be approximately 0.74 kg/ ha (Fig. 2).

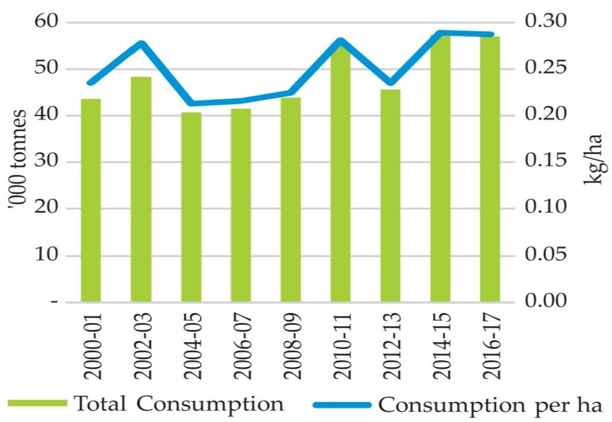

Fig. 2. Chronological changes in total consumption of pesticides in India (Subash et al., 2017)

Ecosystem services and disservices to agriculture

The physiochemical properties of the soil are govern by the farming practices adopted by the farmers during crop cultivation. Many live organisms render their services to improve soil structure and texture. The earthworm enhances the soil structure through soil burrows which creates the pores and by producing casts and increase fertility through partial digestion (Edwards, 2004). Even many insects render their eco-services by facilitating pollination, by decomposition of waste material, and recycling of nutrition etc. (Losey and Vaughan, 2006). The genetic diversity also plays an important role in rendering raw material for natural selection, which helps in evolutionary adaptations (Hawtin, 2000). The indiscriminate and erratic use of synthetic pesticides is responsible for pest outbreaks, resurgence, sudden enhancement in fecundity, and resistance in pest population against pesticides (Thomas, 1999). The ecosystem service and dis-services are depicted in Fig. 3.

The fate of pesticides in the environment

In the environment, the assessment and evaluation of fate of pesticides are essential to determine, as they play an important role in suppressing pest population, simultaneously cause harm to the beneficial microbial population and intoxicate the aquatic and terrestrial resources (Aktar et al., 2009). An ideal pesticide should only be lethal to the target pest, easily biodegradable by the microbes, and should exhibit negligible leaching in the geosphere, but this seems impossible in maximum cases. The fate of pesticides is governed by number of factors such as absorption and uptake by plants, soil adsorption, soil leaching, water runoff, volatilization and wind drift (Aktar et al., 2009). The chance of pesticide movement to off-site is dependent on the formulations, dose rates, chemical properties, modes of application, soil properties, frequency of rainfall or irrigation, and depth to groundwater etc. (Chakrabarti et al., 2006; Aldrich, 2011). The mechanism of retaining pesticides on the soil particle surfaces is adsorption, dependent on the chemical properties of pesticide and soil particulate matters (Aktar et al., 2009). Anionic and neutral pesticides are mostly mobile in soils whereas cationic pesticides exhibit strong adhesion to soil particles (Aldrich, 2011).

Factors affecting toxicity

The application dosage is the most important factor which determines the pesticide's residue in the environment. Lower dosages of pesticides are mostly non-toxic or cause slighter negative effects on the microbial fauna in soil but as the application dosage increase, concentration of residues and the toxicity level also increases. Wang et al. (2008) reported that the excessive use of pesticides such as methamidophos adversely affected the microbial mass and composition, genetic diversity and also the catabolic activities those were estimated by several culturing technique as phospholipid derived fatty acid (PLFA), community-level catabolic profiles (CLCP), amplified ribosomal DNA restriction analysis (ARDRA). The herbicides like glyphosate reduce the population of actinomycetes in humus soil (chernozem), but in wetland soil (gleysol), it enhances their population (Sumalan et al., 2010). The toxicity of pesticides is also impacted by other factors includes various kinds of application methodology like pre-seed or repetitive treatments or by addition of organic manures and on the specific age of the

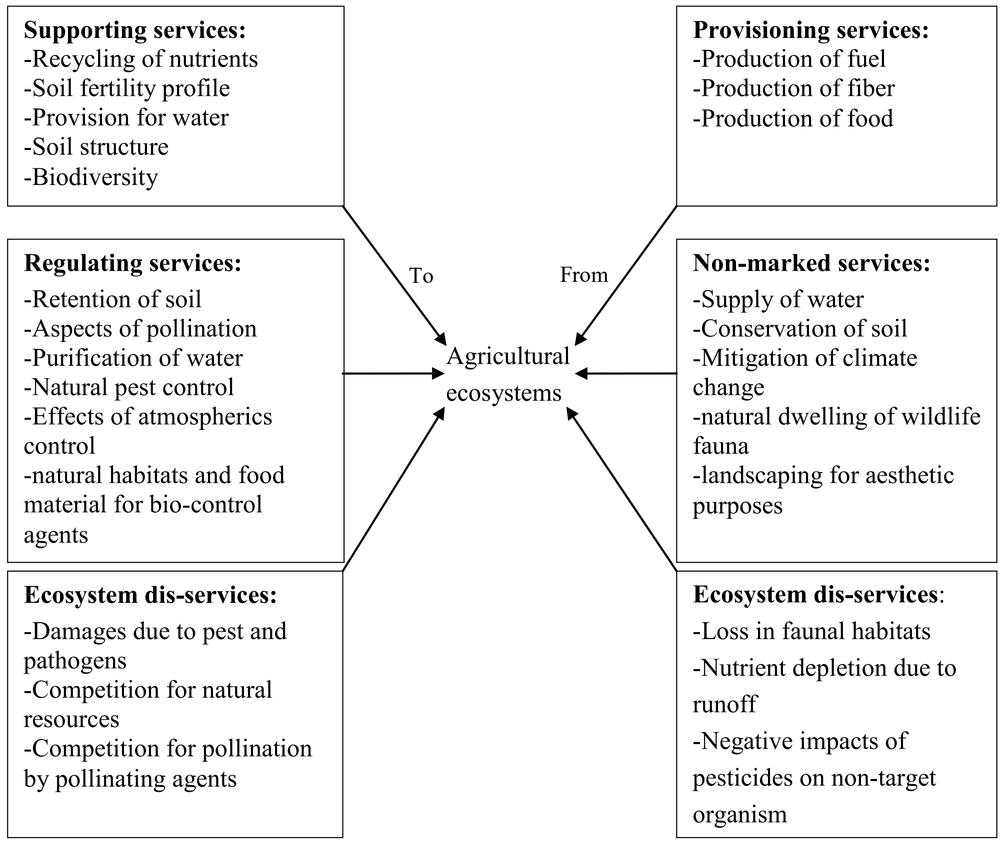

Fig. 3. Ecosystem services and dis-services to agriculture (Zhang et al., 2007)

crop plant (Kalyanasundaram and Kavitha, 2012). It has been reported that the functional biodiversity of bacteria in the soil is reduced by the pre and after seed treatments.

Factors affecting the water pollution

The rate and magnitude of pesticide flow is influenced by both pesticide properties as well as soil properties. The mobility of hydrophobic pesticides and hazard of their discharge into groundwater is addressed by the weak force between pesticide particles and the soil matrix (Wauchope et al., 2001). The hydrogeological conditions of the soil, land use pattern, type of pollutants are responsible for groundwater pollution (Woof et al., 1999). Groundwater vulnerability is a term used to represent the natural ground characteristics with which groundwater may be contaminated by human activities. (US EPA) United States Environment Protection Agency and (NRC) National Research Council (1993) used an idea of groundwater susceptibility along with aquifer sensitivity which does not include characteristics of pesticides and land use or field practices and US EPA developed a DRASTIC system for evaluation of groundwater pollution potential (Aller et al., 1987).

Effect on soil ecosystem services

Pesticides manipulate the nodulation and biological nitrogen fixation in legumes by affecting the infection of nodular bacteria in root fibers of the plant. Herbicide affects the nodulation by adverse effects on rhizobia and plant growth (Zawoznik and tomaro, 2005). Soil profiles possess mobile enzymes and static extracellular enzymes which are an indicator of biological stability, fertility and quality and change in biological status due to pollution (Mayanglambam et al., 2005). Nitrogenase is an enzyme required by the organisms to fix atmospheric nitrogen. Dehydrogenase enzymes occur inside the living microbial cells which are responsible for microbial respiratory processes. The breakdown and alteration of organic matter is carried out by various enzymes as β- Glucosidase, cellulase, and invertase. The urea is hydrolysed into CO_2 and NH_3, a key component of N- cycle is catalyzed by urease enzymes. In Table 1 and 2, a brief summary of effects of various pesticides on biochemical reactions and soil enzymes is listed, respectively.

Microbes

Soil organisms mainly consist of soil microbes like

Table 1. Effects of various pesticides on biochemical reactions in soil

Pesticide	Biochemical reaction	Comments	References
BHC, fenvelerate	C- mineralization	Increased	(Murthy et al., 1991)
Dithiocarbamate	Nitrification	Fungicides inhibited ammonium oxidation	(Hanson et al., 1991)
Chlorinated hydrocarbons	Methanogenesis	Inhibited	(Krumback and Conrad, 1991)
Fenpropimorph	Denitrification	Inhibited	(Svensson and Leonardsson, 1992)
Fungicides	Nitrification	Inhibited nitrification of urea	(Martens and Bremner, 1993)
Cyfluthrin, imidacloprid	Nitrification, S-oxidation, denitrification	Stimuated S- oxidation and inhibited nitrification and denitrification	(Tu, 1995)
Dinoterb	N-mineralization	Enhanced	(Engelen et al., 1998)
Terbutryn, simazine, premteryn, benzoate	N-fixation	Decrease N content and nodulation	(Singh and Wright, 1999)
Butaclor	N-fixation	Initially Increased and later decrease	(Min et al., 2001)
Bensulfuron methyl	N-mineralization	Decreased	(El- Ghamry et al., 2001)
Captan, Benomyl, Chlorothalonil, anilazine	N- mineralization	Increased	(Chen and Edwards, 2001)
DDT, 2-4 D, 2-4 T	N- fixation	Inhibited nodulation	(Fox et al., 2001)
Metalaxyl, Mefonoxam	Ammonification, Nitrification	Increased	(Monkiedje et al., 2002)
Mancozeb, prosulfuron, chlorothalonil	Nitrification	Inhibited	(Arora et al., 2003)
Chlorpyrifos, Quinalphos	Ammonification	Inhibited	(Menon et al., 2004)
Carbendazim, Thiram, Imazethpyr	N-fixation	Inhibit nodulation	(Niewiadomska, 2004)
Pentachlorophenol	Nitrfication	Reduced	(Colores and Schmidt, 2005)
Acetamiprid	Respiration	Reduced	(Yao et al., 2006)
Glyphosate, Imidacloprid and hexaconazole	N-fixation	Toxic to *Bradyrhizobium*sp. strain MRM6	(Ahemad and Khan, 2011)
Fenamiphos	Nitrificiation	Inhibited	(Caceres et al., 2014)

bacteria and fungi, protozoa, nematodes, earthworms and mites etc. Soil organisms have a great influence on nutrient availability by governing number of factors such as mineralization, nutrient immobilization, carbon content in soil, crop residues decomposition and bioturbation. The microfauna has a greater group of enzymes that plays important role in the chemical disintegration of organic matter (Paul and Clark, 1996). Soil microbial biomass which majorly comprises of soil inhibiting bacteria and fungi those are responsible for mineralization and immobilization of soil nutrients. Soil microbial biomass is considered as the source of crucial primary nutrients (C, N, P, S) those are released through their grazing activities of soil fauna. Most prominent method to measure the outcome of pesticides on the soil organism is to determine the change in biological activities i.e. by soil respiration, enzymatic activity or microbial biomass. Effects of various pesticides on the functioning of soil microbial fauna are listed in Table 3.

Collembola

Collembolans are free-living organisms, present in all ecosystem mostly prefer humid conditions. They are responsible for the fragmentation of organic matter and indirectly involved in the decomposition of O.M. Usually, they prefer to consume fungal hyphae and spores, but sometimes also bacteria or plant material. In the terrestrial ecosystem, three invertebrate species are well-known for ecotoxicological assays are *Eisenia fetida* (Lumbricidae), *Folsomia candida* (Collembola), and *Enchytraeus albidus* (Enchytraeidae), as all species has a short life cycle as well as parthenogenetic reproduction. All these qualities make it appropriate for assays (Jansch et al., 2006). Collembolans has less contribution in soil respiration processes and biomass (Coleman et al., 2004) but affecting disintegration of O.M and nutrient cycling and has major influence on microbial ecology and soil fertility (Culik and Zeppelini, 2003). Alves et al. (2014) investigated the effects of seed dressing pesticides on survival and reproduction of *Folsomia candida*, by ecotoxicological tests. Five seed dressing pesticides as imidacloprid, fipronil, thiamethoxam, captan and carboxin+ thiram. Imidacloprid and fipronil were lethal even at lower concentrations which prove as the most toxic pesticides,

Table 2. Effects of pesticides on soil enzymes

Pesticide	Soil enzymes	Comments	References
Captam, thiram	Nitrogenase	Activity of *Azospirillum brasilense* was inhibited	Gallori et al., 1991
Fenvalerate, cuprosan	Nitrogenase	Inhibited	Omar and Abd-alla, 1992
Profenophos	Nitrate reductase	Inhibited	Abdel-Malik et al., 1994
Captan	Nitrogenase	Inhibited	Di Ciocco and Caceres, 1997
Terbutryn, simazine, prometryn	Nitrogenase	Reduced	Singh and Wright, 1999
Glyphosate	Dehydrogenase	At first inhibited but afterwards restored	Andrea et al., 2000
Brominal, selecron	Cellulase	Inhibited	Omar and Abdel-Sater, 2001
Oxafun, Funaben, Baytan	Nitrogenase	Higher dose reduced the activity	Durska, 2004
Carbendazim, imazetapyr, thiram	Nitrogenase	Reduced	Niewiadomska, 2004
Isoproturon	Dehydrogenase	Decrease	Nowak et al., 2004
Isoproturon	Urease	Increase	Nowak et al., 2004
Metalaxyl	Urease, Phophatase	Decrease and first increase and then decreased respectively	Sukul, 2006
Methabenzthiazuron, terbutryn	Nitrogenase	Adversely affect enzymatic activity and reduce nodule number.	Khan et al., 2006
Atrazine, northrin	Dehydrogenase	At low concentration, activity stimulated while at higher concentration it reduces	Nweke et al., 2007
Azoxystrobin, tebuconazole, chlorothalonil	Dehydrogenase	In the low OM soil, activity reduces but not in high OM soil	Bending et al., 2007
Validamycin	Phosphatase and urease	Validamycin affect soil enzyme but recovered soon	Qian et al., 2007
Fenamiphos	Dehydrogenase and urease	Not toxic	Caceres et al., 2009
Endosulfan	Dehyrogenase	Increased	Kalyani et al., 2010
Diuron	Urease	No effect	Romereo et al., 2010
Propiconazole	Cellulase	Reduced from 5-40%	Ramudu et al., 2011
Thiamethoxam	Dehydrogenase, urease and phosphatase	Inhibitory effect on dehydrogenase and phosphatase	Jyot et al., 2015
Azoxystrobin	Urease, dehydrogenases, acid phosphatase, catalase and alkaline phosphatase	Dehydrogenases–resistant while alkaline phosphatase recovered in the soil, rest show inhibitory effect	Bacmaga et al., 2015
Dimethomorph	Dehydrogenases, urease, invertase and acid phosphatase	Urease- no effect Dehyrogenase- Inhibited Invertase- stimulated Acid phosphatase- no effect	Wang et al., 2016

reducing significantly the collembolan reproduction. Frampton and Brink (2007) studied direct and indirect effects of carbamate, synthetic pyrethroid and organophosphate insecticides on collembola and macro-arthropods community, suggested that cypermethrin induced the abundance of collembolan, represent a classical resurgence while primicarb does not affect collembolans.

Mycorrhiza

Mycorrhiza exihibit symbiotic association between a green plant and a fungus. The plant produces sugar by photosynthesis and supplies it to fungi, and in support fungi supply plant water, nutrients as phosphorus from soil. Many experiments revealed that legumes inoculated with both rhizobium and arbuscular mycorrhiza (AM) has an additive effect on plant growth rather than inoculated individually (Vejsadova et al., 1989). It is responsible for increase in P uptake and nitrogen fixation which provides a supplementary benefit towards the synergistic relationship (Brown and Bethlenfalvay, 1987). Abd-alla et al. (2000) has studied

Table 3. Effects of various pesticides on soil microbial fauna

Pesticides	Comments	References
Captan	Fungal hypae length and density, reduction in microbial C and N	Hu et al., 1995
Copper	Soil microbial biomass reduced	Belotti, 1998
DDT	Have adverse effect on bacteria and algal biomass and may not have any impact on fungal count	Meghraj et al., 2000
Captan, chlorothalonil	Suppression of microbial respiration	Chen et al., 2001
Copper	Metabolic quotient was increased which indicates microbial stress. Ratio of microbial biomass to organic carbon was significantly reduced	Merrington et al., 2002
Metalaxyl, Mefenoxam	Bacteria numbers increased with high doses, but toxic towards N fixers	Monkiedje et al., 2002
Glyphosate	Significant reduction in bacteria and fungi population, but increase in actinomycetes. Microbial activity enhanced by 9–19%	Araujo et al., 2003
DDT, arsenic contamination	Significant reduction in the bacterial and fungal count, and biomass carbon was observed	Edvantro et al., 2003
Atrazine, metolachlor	Change in the community structure of actinomycetes and bacteria	Seghers et al., 2003
Arsenic	Decline in the microbial biomass, dehydrogenase activity and soil respiration	Ghosh et al., 2004
Pendimethalin	Decline in the population of nematodes and plant rhizobium in the soil	Strandberg and Scott-Fordsmand, 2004
Chlorpyrifos, dimethoate	Chlorpyrifoshas, has the more lethal effect towards collembolan density	Endlweber et al., 2005
Chlorothalonil, azoxystrobin	Chlorothalonil and azoxystrobinwere found toxic to the *Fusariumoxysporum* strain CS-20(biocontrol agent)	Fravel et al., 2005
Atrazine and metolachlor	Reduction in the microbial counts	Ayansina and Oso, 2006
Diazinon, linuron and mancozeb+ dimethomorph	CFU (colony forming unit) of bacteria and fungi decreased	Cycon and Seget, 2007
Carbofuran, butachlor, diuron, Chlorotoluron, glyphosate, methamidophos, fenamiphos	Carbofuran, glyphosate, methamidophos stimulate while butachlor and femaiphos were detrimental to microbial growth	Lo, 2010
Cypermethrin and thiomethoxam	Detrimental effect on metabolic proceses of soil microorganism	Filimon et al., 2015

the effects of various pesticides like Afugan, Brominal, Gramoxone, Selecron and Sumi Oil on development, nodulation and root colonization of the cowpea (*Vigna sinensis* L.), common bean (*Phaseolus vulgaris* L.) and Lupin (*Lupinus albus* L.) by AM. Application of pesticides restricts the growth of all the legumes but vary with the pesticide and plant species. Growth of the some legumes crops is harmfully exaggerated by indiscriminate and erratic use of pesticides but the extent of the effect modifies with type of plant species and class of pesticides used. In cowpea, after 20 (DAP) days of planting, nodule formation was significantly inhibited and recovered at 40 and 60 days after planting. In all legumes except cowpea, AM root colonization and spores are inhibited, but spore formation was increased in pesticide treated cowpea after 60 DAP.

Earthworms

Earthworms are considered as soil engineers as they are usually present in soil, consume organic matter like plant matter and microfauna. Earthworms are classified in to 3 main ecophysological categories, epigenic, endogenic end anecic. Epigenic earthworms e.g. *Eisenia fetida,* are the non burrowing types and live in the soil litter boundary and consume disintegrated O.M. Endogenic earthworms dwells in the subsoil and makes flat burrows in 10-30 cm of soil, while Anecic earthworms e.g. *Lumbricus terrestris* construct vertical burrows in search of food. Their population depends on soil physiochemical properties such as temperature, pH, salts and moisture. Mostly species are present in neutral to slightly acidic soils. If the soil is more acidic, earthworm would go in to diapause stage easily. Soil acidity is increased by the use of nitrogenous fertilizers, which prove lethal to worms. The effects of various pesticides on biology of earthworm are listed in Table 4.

CONCLUSIONS

Agriculture is the mean to serve the mankind by providing food and generate employment and the top soil is the just the medium to sustain the agriculture. The

Table 4. Effects of pesticides on biology of earthworms

Organisms	Comments	References
Eisenia fetida	Isoproturon affects earthworm at very high concentration	Mosleh et al., 2003
Drawida willsi	Butachlor is reported as lethal to earthworm *Drawida willsi* by have harmful effect on growth and development, sexual maturity and cocoon formation	Panda and Sahu, 2004
Earthworm sp.	Growth rate and borrowing activity of earthworms is reduced with copper which leads to increase in soil bulk densities	Eijsackers et al., 2005
Eisenia fetida	Malathion decreased the spermatic viability in spermatheca and modifying the DNA structure of spermatogonia	Navarro and Obregon, 2005
Apporectodea nocturna and *Allolobophora lcterica*	Imidacloprid, reduced burrowing activity in both earthworm species	Capoweiz and Berard, 2006
Eisenia andrei	Malathion + primiphos methyl show antagonistic effect against *Eisenia andrei*	Stepic et al., 2013
Eisenia fetida	Imidacloprid has a harmful effect on *E. fetida* as it affects the antioxidant defense and digestive system	Zhang et al., 2014
Eisenia fetida	The toxicity of 5 pesticides (trichlorfon, dimethoate, carbendazim, tebuconazole and prochloraz) was evaluated on different lethal and sublethal end ponts of the earthworm	Rico et al., 2016
Eisenia fetida	The herbicide tribenuron-methyl and fungicide tebuconazole have exhibited antagonistic effects on soil earthworm *Eisenia fetida*	Chen et al., 2018

topsoil needs utmost care as the quality and fertility of the soil determines the yield of crop. By adaptation of modern days tactics like uses of synthetic fertilizers and pesticides, have enhanced the yield output, but the same time many problems related to health of soil-ecosystem have evolved. The directive of agricultural development is to nourish and deliver surplus nutrition to the growing population without negotiating with the health of environment. Widespread and erratic application of synthetic chemical fertilizers and pesticides and their leaching in to groundwater lead to soil and water pollution. In cultivated lands, the soil ecosystem services provided by microfauna are affected by the application of toxic and persistent chemical pesticides which ultimately changes the soil properties. Synthetic pesticides are harmful to soil ecosystem and human health as derivatives of pesticides are persistent and long lasting in soil which negatively affect the growth and development, diversity and biochemical processes of microbes. Pesticides also reduce soil fertility by which crop yield is affected. A rational use of the pesticides is important as harmful effects are observed when the applied doses are more than the recommended rates. To reduce the hazardous effects on the environment and humans, the farmers, distributors, industry, stakeholders and policymakers should educated and trained for rational use of pesticide. Soil microbial population provides a vital link in the natural food web. Thus, any alteration in the composition and soil microbial population can disturb the trophic structure and cause a risk to global food security. Well-designed trials and experiments are the need of the hour to examine the long term consequences of the pesticides on the health of the microbial communities as well as their eco-toxicological effects in the soil environment.

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