Impact of Agrochemicals on Soil Biota and Ways to Mitigate it: A Review

ABSTRACT

Agricultural production is largely based on the use of agrochemicals in order to minimize pests, pathogens, and undesirable weeds toward increase production. In the current situation, however, several threats are emerging that threaten food security, human and environmental health, ecological balance, and soil biodiversity. Agrochemicals may shift beneficial microorganisms in the community over time, with potentially dangerous consequences, such as the development of antibiotic resistance. Farming systems utilizing agrochemicals might adversely affect soil microorganisms responsible for nutrient cycling processes, such as: nitrogen fixation, phosphorus solubilizing, and others. Some agrochemicals reduce soil enzyme activity and biochemical reactions, which are key indicators of soil microbiology. In this review, we explore how applied agrochemicals affect soil microbes and biochemical health attributes under different cropping systems, as well as ways to overcome the negative impacts of agrochemicals.

Keywords: Agrochemicals, Soil microbes, Environmental health, Biotransformation, New generation pesticides

1. INTRODUCTION

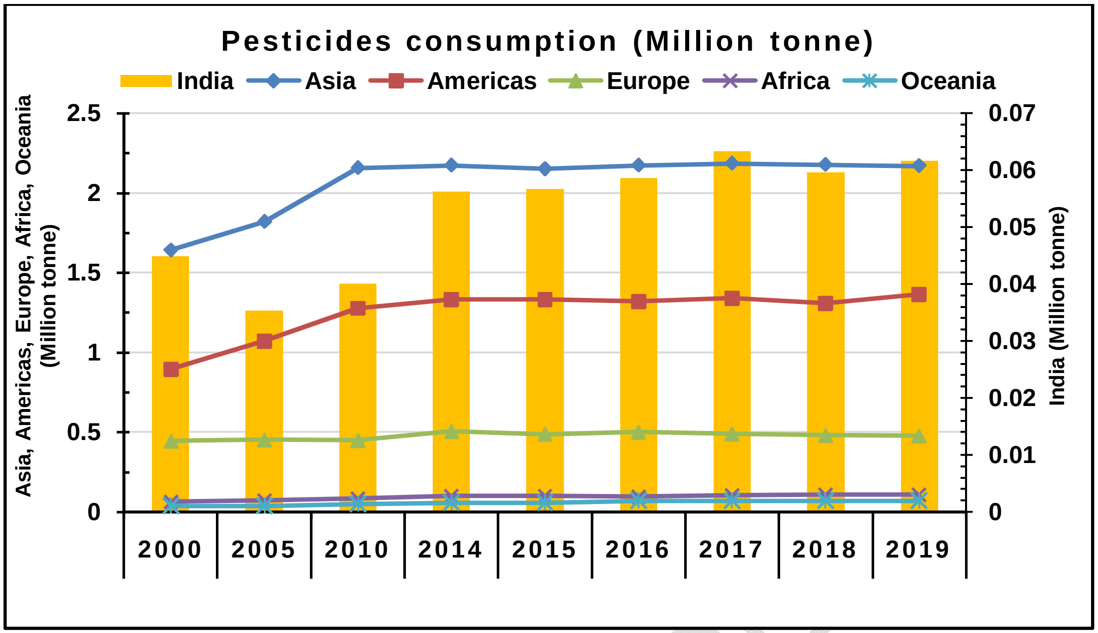
Existing farming practices in many countries make heavy use of toxic agrochemicals, which are discharged directly or indirectly into the soil, air, and water [1]. In agriculture, agrochemicals are chemicals that humans use to manage the ecosystem, supply nutrients, and control harmful pests, pathogens, and unwanted weeds in order to increase the productivity of the ecosystem. The term agrochemical is typically used to describe insecticides, herbicides, fungicides, algaecides, rodenticides, molluscicides, nematicides, synthetic fertilizers, soil conditioners, linings, and plant growth regulators [2]. Globally, pesticide consumption is increasing day by day. In 2000, pesticide consumption was 3.08 MT, and in 2019 it was 4.2 MT, an increase of 36% (Fig. 1) [3]. Currently, agrochemicals are being used injudiciously, which can cause ill effects on soil microbial growth, activity, and count [4]. Humans are generally safe from ammonia at low concentrations, but anhydrous ammonia in high concentrations may prove fatal if drifted over long distances.

As part of maintaining soil fertility and productivity, soil microbes degrade organic matter, recycle nutrients, form humus, stabilize soil structurally, fix nitrogen, promote plant growth, and control disease through biochemical transformations such as ammonification, nitrification, phosphorus solubilization [5]. It has been demonstrated that pesticide use in arable farming contributes to soil and environmental contamination [6]. Agrochemicals applied to soils are not reached by 99.9% and persist in the soil ecosystem for a long period of time, which leads to their biomagnification and bioaccumulation, whereas only 0.1% reach target organisms [7]. Harris and Sans found that microbial activity and agrochemical residues are commonly present in the upper layer of soil [8]. Microbes are affected by agrochemicals, even if they are used in low quantities and concentrations, as well as their chemical, biological, and biochemical properties. According to Cycon *et al*. [9] in addition, it is not easy to predict how agrochemicals interact with soil microorganisms based on their chemical structure. Most agrochemicals have no effect on microbes when sprayed at normal rates, depending on the type, quantity, and soil conditions while, some agrochemicals increase the growth and activity of microbes [10].

Developing an ecologically sound strategy to maintain soil health and advance food security without compromising soil biodiversity on a global scale with the responsible use of agrochemicals is advised by the convention on integrated pest and nutrient management, which also proposed some alternative ways to address the growing demand for high-quality, protein-rich food resources by a growing global population [11].

2. INDIA'S AND THE WORLD'S PESTICIDE CONSUMPTION

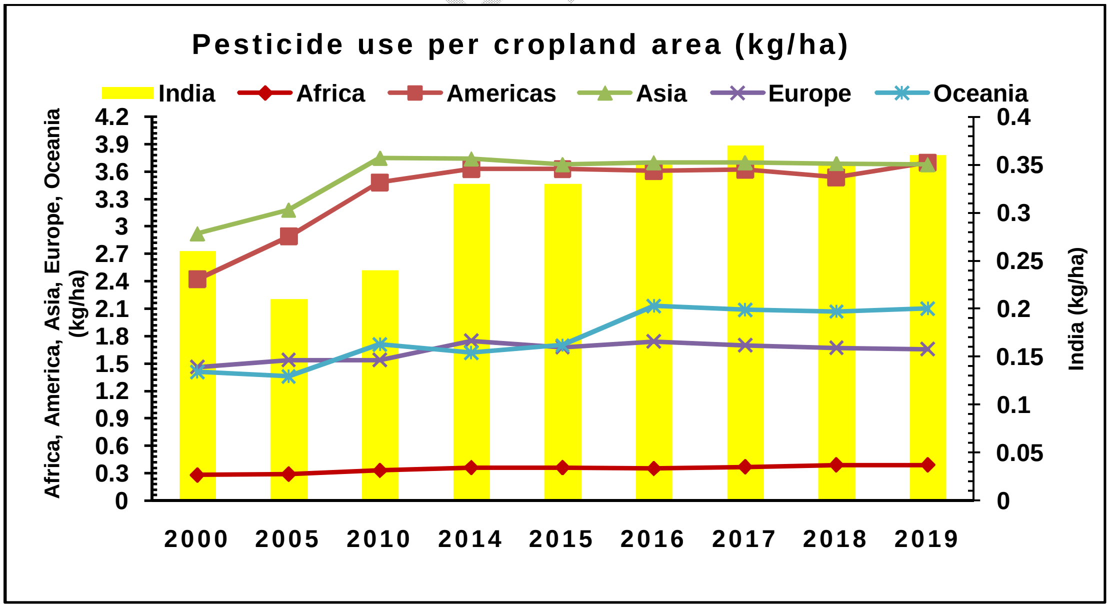
There is an increase in pesticide consumption globally every day. The total consumption of pesticides in 2000 was 3.08 MT, which increased to 4.2 MT in 2019, which is an increase of 36%. The increase occurred approximately between 2000 and 2012, followed by a plateau. Asia consumed the most pesticides in total, followed by the Americas, Europe, Africa, and Oceania. A few provinces contributed to the world total over time, but Asia, the leading contributor, remained constant at 52-53%. As a percentage of global pesticide consumption, the Americas increased from 29% to 33%, but Europe decreased from 14% to 11%. Over time, Africans and Oceanians used minor amounts of pesticides, but Oceania had the highest growth in pesticide applications (+85%). During the 2000s and 2019s, India consumed 61.702 thousand tons (technical grade) of pesticides, an increase of 37.24%. Pesticide usage per cropland area went up 28% in the 2000s, to 2.6 kg/ha, and remained unchanged after 2010, despite some regional differences (Fig. 2). Among the provinces, Asia was the only one where pesticide application did not increase from 2010 to 2019. During the period from 2000 to 2019, pesticides were applied at a rate of 0.36 kg/ha in India, a 0.38% increase [3].



Source: (FAOSTAT, 2020) [3]

Fig. 1. Pesticide uses by region

Note: Percentage on the figure indicate the shares in the total; they may not tally due to rounding



Source: (FAOSTAT, 2020) [3]

Fig.2. Pesticide use per cropland area by region

3. EFFECTS OF AGROCHEMICALS ON SOIL MICROBES

3.1 Effect of Agrochemicals on Bacteria and Actinomycetes:

3.1.1 Herbicides:

In organic matter degradation and enzyme activity, microbes play an important role. There is a detrimental effect of herbicides on soil microbial populations within 7 to 30 days after application, depending on the type of herbicidal molecules present [12]. Microbial counts in soil are affected by herbicidal doses and their molecules [13]. DeLorenzo *et al*., states that herbicides interfere with vital processes such as respiration, photosynthesis, biosynthesis reactions, growth, cell division, and molecular composition in beneficial microbes [14]. According to Engelen *et al*. [15] dinoterb herbicide application adversely affects soil microbial biomass and stimulates nitrogen mineralization. Pampulha and Oliveira [16] reported that the combination of 60% bromoxynil and 3% prosulfuron had an adverse effect on microbial counts in soil with a long-term negative effect on dehydrogenase activity. By Iqbal *et al*. [17] reported that butachlor application has adverse effects on methanogenic bacterial counts. Ani *et al*. [18] reported that in the first week of incubation, Glyset (Glyphosate 48%) 50ppm, 100ppm, and 200ppm reduced the bacteria count by 4%, 11%, and 13%, respectively. At the 7th week, bacterial counts decreased by 6%, 9%, and 9%, respectively, while the actinomycetes population decreased by 5%, 7%, and 22% respectively at the 1st week of incubation, and at the 7th week, the population decreased by 7%, 9%, and 10%, respectively. Triazines (Atrazine, terbutryn, simazine, prometryn, and bentazone) due to persistence nature adversely affects soil microbial counts and rhizobacterial functions [19, 20]. Polyoxymethylene amine increases glyphosate herbicide toxicity more than glyphosate alone due to formation of secondary metabolites by physical and biochemical transformations [21].

3.1.2 Insecticides and fungicides:

Ani *et al*. [18] applying alphacypermethrin 10% (Miraj) insecticide at 50 ppm, 100 ppm, and 200 ppm reduces actinomycetes counts by 54%, 56%, and 60% in 1st and 7th week, by 63%, 64%, and 69% respectively, while malathion at 50ppm, 100ppm and 200ppm were reduced actinomycetes by 34%, 36%, and 40% correspondingly at 1st and 7th week by 37%, 42%, and 50%. The bacterial counts were reduced by 40%, 42%, and 59% by malathion at 50ppm, 100ppm, and 200ppm in 1st week while, decreases remained at 32%, 38% and 41% in the 7th, 10th and 13th week of application. According to Seget *et al*. [22] oxytetracycline (bactericide) or captan (fungicide) have detrimental effects on bacterial counts, but total bacterial biomass remains unchanged. Odokuma and Osuagwu [23] reported that lindane and dieldrin are more toxic than organophosphates such as pirimphos methyl and malathion on *Nitrosomonas*, *Nitrobacter*, and *Thiobacillus*. Wesley *et al*. [24] and Nicoleta *et al*. [25] detected an increase in microbial growth at lower doses (10 ml) of insecticide (Thionex, Best, monochrotophos, quinalphos, and cypermethrin) but remained lethal to them at higher doses (15-20 mL) and inhibited their growth and survival. *Azotobacter* is adversely affected by phosphamidon, malathion, fenthion, methylphosphorothioate, and parathion, and by carbofuran, phorate, and disulfoton in soil. Rhizobacterial counts are negatively affected by chlorpyrifos, imidacloprid, cypermethrin, endosulfan, and carbofuran and mostly destroyed by chlorpyrifos [26].

3.1.3 Synthetic Fertilizers:

Chemical fertilizers decrease soil fertility and product quality because they negatively affect microbial counts and ecosystems in soil. Zainuddin *et al*. [27] observed that the highest soil microbial counts were found after applying BF100 (100% biofertilizers), even though BF70 (biofertilizer 70% with 30% chemical fertilizer) had a slightly lower microbial count (3.2444) for bacteria compared to CF100 (100% chemical fertilizer) was (2.2372). Compared to unfertilized treatments, organic manures increased microbial counts, CO_2 emissions, and N mineralization. A zinc oxide nanoparticle application reduced the number of colonies of bacteria and fungi in the soil and 39 and 43% of CO_2 emissions from FYM and poultry manure, respectively [28].

3.2 Effect of Agrochemicals on N-Fixing Microbes:

Nutrients are made bioavailable by nitrogen-fixing microbes. Rhizobacteria also lose their ability to fix atmospheric nitrogen due to agrochemicals. Govedarica *et al*. [12] found that herbicides affect nodulation, bacteroid formation, nitrogenase activity, and ATP synthesis, all of which affect biological nitrogen fixation (BNF). A similar finding has been supported by Meena *et al*. [11] which finds that rhizobacterial infection can be disrupted or root fibers can be affected, which affects node formation and infection in legumes. Iqbal *et al*. [17] reported that herbicides also affect *Rhizobium* phytochemical signaling that affects BNF and cell morphology. Paraquat and glyphosate are non-selective herbicides that reduce N-fixation and prometryne affects the biological activity of *Azotobacter* and some other bacterial counts in soybean [29]. As a result of the 2,4-D application, blue-green algae (BGA) growth is reduced and the nitrification and BNF process is inhibited in beans and affects the *Rhizobacterial* population [30]. Nodule-forming bacteria cannot grow and survive when trifluralin, metribuzin, imazethapyr and linuron were applied found that decreased the nitrogenase activity of nodule-forming bacteria and stimulated their development of resistance [31, 32]. It has been found that herbicides used under chickpea decrease the microbial counts of rhizobium [33].

Most of the copper (Cu) based fungicides (Captan and apron SD) have detrimental effects on N-fixing bacteria [34, 35]. Application of mancozeb and chlorothalonil within 48 hours can influence nitrification and denitrification processes [36]. Using triarimol and captan reduces the growth of *Aspergillus species* as well as the development of plants [37]. The application of thiobencarb at 2 to 4 mg/kg inhibits the growth and survival of *Azospirillum*, *Azotobacter*, and anaerobic nitrogen fixers under alluvial soil [38].

3.3 Effects of Agrochemicals on Arbuscular Mycorrhizal Fungi (AMFs):

AMFs are symbiotic associations between fungi and roots of higher plants, which enhance nutrient uptake, particularly P, nitrate (NO_3), and ammonium (NH_4), as well as improve soil aggregate stability [39]. It has been shown that mycorrhizal fungi and bacterial counts are affected by benzoyl application [40, 41]. Monkiedje [42], found that metalaxyl is effective at promoting the colonization of AMFs in the roots of soybeans and maize.

As a result of applying glyset 200ppm, fungal counts were reduced by 20% and 13% in the 1st and 7th weeks, 50ppm, 100ppm, and 200ppm of Miraj insecticide, fungal counts were reduced by 60%, 61%, and 63%, respectively, 1st week after application. After 7th week after application, the decrement was 48%, 50%, and 62%, respectively [18]. Malathion at 50ppm, 100ppm, and 200ppm reduced fungal counts by 56%, 62%, and 66%, in 1st week and 58%, 64%, and 65% were in 7th week, respectively.

Mycorrhizal spore germination and propagation are negatively affected by oryzalin, trifluralin, and oxadiazon [43]. In greenhouse conditions, glyphosate application also decreased mycorrhizal counts by 40% [44]. According to Zainuddin *et al*. [27] the fungal counts were highest (2.66), in BF70 treated plot H', compared to BF100 (1.97) and CF100 (2.37) treated plots.

3.4 Effects of Agrochemicals on Cyanobacteria and Algae:

As important microbes that support aquatic and terrestrial ecosystems, algae and cyanobacteria play an important role in the food chain. When pesticides and fertilizers are used in combination at higher concentrations, harmful cyanobacterial blooms (HCBs) are intensified. Azoxystrobin (AZ), a common strobilurin fungicide, may promote the growth of cyanobacteria by entrapping eukaryotic intrants (Chlorophyta) and inhibiting parasites and pathogens [45]. Algae that fix atmospheric nitrogen and carbon dioxide are the most prevalent nitrogen fixers in soil and water environments [46]. Mallavarapu [47] and Megharaj *et al*. [48] found that dichloro-diphenyl-trichloroethane (DDT) reduces soil algal counts as well as replaces cyanobacteria with green algae and decreases activities of beneficial soil enzymes (dehydrogenase and arylsulfatase). In addition, trichlorfon affects nitrate uptake by Anabaena and decreases chlorophyll, phycobiliprotein, and nitrate uptake by other cyanobacteria.

Caceres *et al*. [49] found that organophosphorus insecticide fenamiphos was degraded by soil algae (*Chlorella, Scenedesmus sp., Chlamydomonas sp., Stichococcus sp.*) and cyanobacteria (*Nostoc sp., Nostoc muscorum, Anabaena sp.*). The application of pesticides *i.e.*, lindane, pentachlorophenol, isoproturon, and methyl parathion have acute toxic effects on the growth and survival of *Chlorella kesslerei* and *Anabaena inaequalis* and decrease the counts in soil [50].

4. WAYS TO MITIGATE THE EFFECT OF AGROCHEMICAL ON MICROBES:

Agrochemicals and their derivatives have been shown to have detrimental effects on microbial counts ever since they were invented [26]. Rapid and consistent diagnostic methods have made it possible to better understand the long-term effects of agrochemicals on soil and ecosystems. Due to the ever-growing knowledge of agrochemicals related to health and environmental concerns, new judicial activities are being used as a sign of perfection and disease control [51]. Despite the threat of agrochemicals and their pollution, biotic pest control remains an ecologically friendly means of controlling pests. The following are some of the most important genuine management approaches:

4.1 Use of biopesticides and Cultivation of Transgenic Crops:

In Integrated Pest Management (IPM), biopesticides are among the alternative methods for altering and reducing the effect of agrochemicals on soil microbes. Biopesticides, which are products derived from animals, plants, and microbes *i.e.*, bacteria and viruses, are crucial in the biological control of insects and diseases. The transgenic plants exude lethal compounds into their environment, causing apprehensions around their environment because of possible antagonistic properties. Transgenic crops contain antimicrobial compounds *i.e.*, chitinases, glucanases, lysozymes, thionins, defensins, and systemic acquired resistance gene products, harbor antibiotics, herbicide resistance genes, or produce novel toxins for pest resistance. Bacillus thuringiensis and its products, baculoviruses, rotenone, pyrethrin, nicotine, and azadirachtin are among the most commonly used biopesticides. Biocontrol agents such as *Trichogramma*, a fungus that parasitizes and preys on eggs, and *Bacillus thuringiensis* have commonly been used with *Trichoderma* [52]. The entomopathogenic nematodes (EPNs) of the genera *Heterorhabditis sp*. *Steinernema* *sp*., as well as other potent agents, are effective against insect pests of Diptera, Coleoptera, Lepidoptera, and Orthopteran within 24 hours [53].

4.2 Use of microbes associated with plants:

Microbes associated with plants contribute to food security, safety, agricultural production, and ecological balance. In a study published by Dwivedi *et al*. [60] in 2009, showed that arbuscular mycorrhizal fungi (*Glomus spp.*) with phenazine and diacetyl phloroglucinol increased *Pseudomonas fluorescens* counts, while an unknowing *Alcaligenes faecalis* strain SLHRE425 influenced soil arbuscular mycorrhiza root colonization and numbers. CHA0 and Pf-5 strains of Pseudomonas fluorescens secrete many antibiotics that suppress plant pathogens [61]. Karpunina *et al*. [62] found that growth inhibition in *Rhizobium leguminosarum* and *Bacillus subtilis via* lectins I and II (at a concentration of 1–10 μg/mL) isolated from the nitrogen-fixing soil bacterium *Paenibacillus polymyxa*. Furthermore, lectin I suppressed the growth of *Azospirillum brasilense* and *Erwinia carotovora* subsp. *citrulis*, while lectin II suppressed the activity of *Xanthomonas campestris* and *Azospirillum brasilense*. The seed dressing with Pseudomonas at 3 g/kg results in increases in fungal counts (12.27-104 CFU), actinomycetes (11.4-105 CFU), and *Bradyrhizobium japonicum* population over control [63].

4.3 Plant and Microbial By-Products:

Neal *et al*. [54] report that some plants secrete substances that stimulate or suppress soil microbial counts. Mycorrhizal fungi of the order Glomeromycota are stimulated by strigolactone exudates (a plant sesquiterpene) [55]. Rhizosphere N-fixing bacteria are increased by flavones and flavonoids released by legumes [56]. Besides controlling a wide range of pests, neem and its derivatives provide nutrition for soil microbes and improve the soil's physicochemical properties and contains compounds that act as antifungal and antimicrobial [57]. It was reported by Ipsilantis *et al*. [58] that pyrethrum, terpenes, and spinosad adversely affect AMF in pots and in the field, affecting the fungi's colonization ability and structure. The Azotobacter population is stimulated by neem cake and azadirachtin [59].

4.4 Use of new generation pesticides:

New-generation insecticides consist of the reformulation of existing insecticides and the development of new types, mainly organic and nano pesticides. It has been shown that new pesticides can be more effective against pests than traditional pesticides, including propolis and natural base pesticides as well as chitin inhibitors, pheromones, and metamorphosis-disseminating sulfonylureas as well as dinitroanillines and triazoles (Technology Information, 2009). A new preparation of the herbicide Paraquat has been developed by Heylings *et al*. [64] which consists of an improved concentration of the active constituent, magnesium sulfate, and gel-forming ingredients, namely alginate, which delay the engagement of the consumed substance. There is substantial interest in the preparation of green, safe, and effective pesticides based on intellectual, receptive, ecological, and biocompatible ingredients. Plant-incorporated protectants (PIPs), or pesticidal materials produced by plants with additional inherent resources, have been developed by Abdollahdokht *et al*. [65].

The advantages of nanomaterials (NMs) in the arena of agrochemicals include their smaller particle size, higher specific surface area, surface structure, solubility, and chemical configuration, nanomaterials and nanotechnology can overcome many of the shortcomings of conventional agrochemicals, including bioavailability, photolysis, and organic solvent pollution [66].

5. CONCLUSION

Emerging nations consider agrochemicals and their use as magical ammunition. Several chemicals and their derivatives persist in soil for an extended period of time, making agrochemicals a serious threat to soil ecosystems and human health. The application of agrochemicals, primarily pesticides, disrupts soil aggregation and fertility by disrupting soil microbial flora. To avoid uncaring pesticide use, biopesticides, organic pesticides, novel biocontrol agents, and nano pesticides must be encouraged. As a result of their unidentified environmental concerns and undesirable ecological effects, nano pesticides are questionable for use in pesticides. To better understand pesticides' long-term effects on microbial communities and their long-term eco-toxicological effects in the soil, well-designed experiments are needed.

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