Review Article

Impact of Agrochemicals on beneficial microorganisms and human health

Comment [u1]: Do mention the site of study as the paper is mainly concerned with the case studies of India

Abstract

Agrochemicals, including fertilizers, pesticides, and herbicides, are widely used in agriculture to improve crop yields and protect plants from pests and diseases. There is growing concern over their impact on beneficial soil microorganisms and, indirectly, on human health. This review aims to provide an in-depth analysis of the effects of agrochemicals on soil microbial communities and human health, focusing on recent scientific research and case studies. Exploring various agrochemicals can disrupt microbial diversity, population, and functionality, affecting crucial soil processes and, in turn, ecosystem health. We delve into the pathways of human exposure to agrochemicals and the potential health implications. To mitigate the adverse effects of agrochemicals, the review highlights several alternative approaches, including the use of organic fertilizers and pesticides, precision agriculture, and genetically modified crops. Despite these advancements, research gaps persist in understanding the complex interplay between agrochemicals, beneficial microorganisms, and human health, particularly in the changing agricultural practices and climate conditions. We argue that interdisciplinary, long-term studies are needed to fill these gaps and develop sustainable, health-conscious agricultural practices. The review is intended for researchers, policymakers, and agricultural practitioners seeking to understand and address the environmental and health impacts of agrochemicals.

Keywords: *Agrochemicals, Soil Microorganisms, Human Health, Sustainable Agriculture, Genetically Modified Crops*

Introduction

Agrochemicals, also known as agricultural chemicals, are substances used in agriculture to promote plant growth and protect crops from pests and diseases (Damalas & Eleftherohorinos, 2011). These chemicals are classified into various types, including but not limited to, fertilizers, pesticides, plant growth regulators, and soil conditioners (Aktar *et al.*, 2009). These play a pivotal role in modern agriculture by enhancing productivity, ensuring food security, and supporting the global economy (Carvalho, 2017). The use of agrochemicals also raises concerns due to their potential environmental and health impacts. One of the lesser-known but highly significant aspects of this impact is the effect of agrochemicals on beneficial microorganisms. Microorganisms are fundamental to the fertility of the soil and the nutrient availability for plants (Berendsen *et al.*, 2012). They participate in numerous processes, including organic matter

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decomposition, nutrient cycling, disease suppression, and plant growth promotion (Philippot *et al*., 2013). Apart from their crucial role in soil health, beneficial microorganisms, such as certain bacteria and fungi, have significant effects on human health as well. The gut microbiota, for example, is essential for digestion, immune system functioning, and even mental health (Cani, 2018). Disruption of these beneficial microbial communities, either through diet or environmental exposures, could have substantial health impacts.

A growing body of evidence suggests that the use of agrochemicals may be negatively affecting beneficial microorganisms both in the soil and within the human body (Wagg et al., 2019). Understanding the relationship between agrochemicals, beneficial microorganisms, and human health is, therefore, of paramount importance. This review aims to synthesize current knowledge on this topic, elucidate the mechanisms of agrochemical-induced harm, and identify opportunities for further research and mitigation.

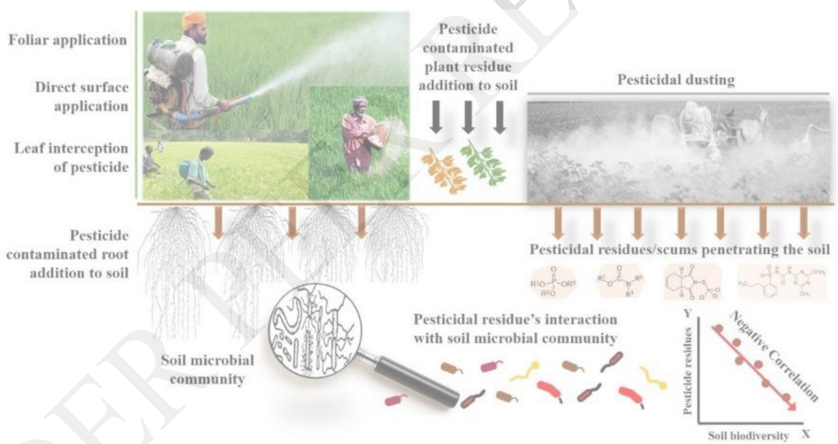

Image 1: A schematic illustration depicting the response and effects of pesticides on soil microbial communities and biodiversity. (**Source:** Meena *et al.,* 2020)

Agrochemicals

Agrochemicals encompass a broad range of substances, each with a distinct role in agricultural management. Fertilizers, including nitrogenous, phosphatic, and potassic types, provide essential nutrients to the soil, thereby enhancing plant growth and productivity (Pahalvi *et al*., 2021). Pesticides, including insecticides, herbicides, and fungicides, are employed to protect crops from pests and diseases, thereby securing crop yields (Carvalho, 2006). Other agrochemicals, such as plant growth regulators and soil conditioners, fine-tune the growth and developmental processes of crops and improve soil physical properties, respectively (Saraf, 2014). The use of agrochemicals is widespread across the globe, reflecting their crucial role in modern agricultural practices. In 2018, the global agrochemical market was estimated to be worth $239.85 billion and projected to reach $365.16 billion by 2027. This growth is driven by the rising global population and the consequent demand for increased food production.

Beneficial Microorganisms

Beneficial microorganisms encompass a wide array of bacterial, fungal, protozoan, and algal species that contribute positively to soil health and plant growth (Table 1). Bacteria such as Rhizobium and Azotobacter contribute to nitrogen fixation, while others like Pseudomonas and Bacillus species play roles in phosphorus solubilization and biological control of plant diseases (Mohammed, & Toama, 2019). Fungi, including species of Mycorrhiza, enhance nutrient uptake by plants and increase their tolerance to environmental stress (Bahadur *et al.*, 2019). Beyond their soil and plant-related roles, beneficial microorganisms also have significant implications for human health. The human microbiome, comprising trillions of microbial cells, is critical for various physiological functions, including digestion, immune regulation, and even mood regulation (Cryan *et al.*, 2019). Disruptions in these microbial communities are associated with a range of health conditions, from inflammatory bowel disease to mental health disorders (Aden *et al*., 2019).

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Table:1 Beneficial Soil Microorganisms and their Functions

Comment [u4]: Mention the differences between plant and animal beneficial microbiomes.

Type of Microorganism	**Example Species**	**Benefits**	**References**
Bacteria	Rhizobium spp.	Nitrogen fixation, enhances plant growth	Lugtenberg and Kamilova, 2009
Fungi	Mycorrhizal fungi	Improves nutrient and water uptake, promotes plant growth	Smith and Read, 2008
Protozoa	Amoebae, flagellates, ciliates	Regulates bacterial populations, nutrient cycling	Bonkowski, 2004
Algae	Cyanobacteria (blue-green algae)	Nitrogen fixation, soil stabilization	Whitton and Potts, 2007

Relationship between Agrochemical Use and the Health of Beneficial Microorganisms

Recent research has shed light on the potentially detrimental effects of agrochemicals on beneficial microorganisms. For example, certain pesticides have been shown to decrease the abundance and diversity of soil microorganisms, affecting nitrogen fixation and other key soil processes (Hussain *et al*., 2009). Agrochemicals can also potentially influence the human microbiome. Exposure to glyphosate, a commonly used herbicide, has been suggested to affect gut microbiota composition, with potential implications for human health (Ruuskanen *et al*., 2020). The interaction between agrochemicals, beneficial microorganisms, and human health is complex and depends on various factors, including the type and concentration of agrochemicals used and the specific microbial communities present. Understanding this interplay is crucial for making informed decisions about agrochemical use and managing their potential impacts on environmental and human health.

Impact of Agrochemicals on Beneficial Microorganisms

Extensive research indicates that agrochemicals, particularly pesticides and fertilizers, can have a profound impact on soil microorganisms (Table 2). Pesticides, such as neonicotinoids, have been found to decrease the abundance and diversity of certain soil microbial communities (Zhao *et al.,* 2020). Similarly, repeated application of nitrogenous fertilizers can lead to an imbalance in microbial communities, favoring certain bacteria over others (Leff *et al*., 2015).

Table:2 Impact of Selected Agrochemicals on Beneficial Soil Microorganism

Agrochemical	**Beneficial Microorganism**	**Impact**
Glyphosate (herbicide)	Rhizobia (nitrogen-fixing bacteria)	Can inhibit growth and symbiotic performance (Santos & Flores, 2018)
Mancozeb (fungicide)	Mycorrhizal fungi	Can reduce colonization and impair function (Sabatino *et al*., 2020)
Imidacloprid (insecticide)	Arbuscular mycorrhizal fungi	Can suppress colonization and spore formation (Wu *et al*., 2020)
Atrazine (herbicide)	Nitrosomonas spp. (nitrifying bacteria)	Can suppress population and activity (Ge *et al*., 2010)

Case Studies

Case Study 1: Impact of Pesticides on Soil Microbes in Punjab

Punjab, one of the most fertile regions in India, has experienced heavy pesticide usage due to intensive agricultural practices. A study by Kaur *et al.* (2010) revealed that the excessive use of pesticides significantly reduced the diversity and population of nitrogen-fixing bacteria and phosphate solubilizing microorganisms in the soil. This decline in beneficial microorganisms can potentially affect soil fertility and crop yield in the long term.

Case Study 2: Bioaccumulation of Pesticides in West Bengal

In West Bengal, the heavy use of organophosphorus pesticides in rice paddy fields has led to bioaccumulation of these pesticides in different trophic levels, which ultimately reach humans through the food chain. Bhattacharya *et al.* (2005) showed that this bioaccumulation has not only affected the soil microbial diversity but also led to serious health concerns like neurotoxicity and cancer in humans.

Case Study 3: Impact of Organic Farming Practices in Sikkim

In contrast to these detrimental impacts, the state of Sikkim provides a positive example of how alternative farming practices can enhance soil microbial diversity. Sikkim is the first Indian state to implement 100% organic farming practices. A study by Ghosh *et al.* (2019)

showed that the transition to organic farming significantly enhanced soil microbial activity and diversity, leading to improved soil health and crop yield.

Long-term Impacts on Microbial Diversity, Population, and Function

Case Study 1: Impact of Fertilizers on Nitrogen Cycle in Punjab

Punjab's intensive farming practices heavily depend on chemical fertilizers. Ghosh *et al.* (2016) in their decade-long study observed that continuous application of urea (a nitrogen-based fertilizer) led to an imbalance in the population of nitrogen-fixing and nitrifying bacteria. This alteration not only affected the nitrogen cycle in soil, but also led to increased nitrous oxide emissions, a potent greenhouse gas, thereby contributing to global warming.

Case Study 2: Effect of Pesticides on Microbial Activity in the Gangetic Plains

In the Gangetic plains, where rice and wheat cropping systems dominate, long-term pesticide use has been reported to adversely impact microbial population and diversity. Bhattacharyya et al. (2008) found that the continuous application of a mix of organochlorine, organophosphate, and synthetic pyrethroid pesticides over 5-7 years significantly reduced the soil microbial biomass and enzyme activities, affecting overall soil health and crop productivity.

Case Study 3: Impact of Organic Farming in Kerala

In the Indian state of Kerala, where a shift towards organic farming has been observed, a long-term study by Rajan *et al*. (2017) found that organic amendments led to an increase in microbial biomass and enhanced enzyme activities over time. The study highlights the potential of organic farming in mitigating the negative impacts of agrochemicals on soil microbial communities.

Impacts on Broader Ecosystem

The changes in microbial communities induced by agrochemicals have repercussions beyond soil health and crop productivity. Soil microbes play a pivotal role in global carbon and nitrogen cycles (Porporato *et al*., 2003). Thus, changes in these microbial communities could impact these biogeochemical cycles and potentially contribute to climate change. Furthermore, alterations in soil microbial communities could indirectly affect above-ground biodiversity, including insects and larger fauna, shaping the overall ecosystem structure and functioning (Murray *et al*., 2006).

Impact of Agrochemicals on Human Health

Direct Exposure in Indian Agricultural Workers

In India, agriculture employs a substantial portion of the population, exposing many to the direct risks of agrochemical use. These workers often lack appropriate protective equipment and education about safe handling practices. A study by Shetty *et al.* (2011) reported high incidence of symptoms related to pesticide exposure, such as headache, dizziness, and skin irritation, among farmers in West Bengal who frequently handled pesticides. This demonstrates the high risk of direct exposure and its health implications among agricultural workers in India.

Indirect Exposure through Food and Water Contamination

Indirect exposure through food and water is a significant concern for the general population in India. Craddock *et al.* (2019) found detectable levels of multiple pesticide residues in vegetables sold in markets across the country. In a study conducted by Bedi *et al.* (2013), a significant amount of organochlorine pesticide residues were detected in the breast milk of women from rural areas in Punjab, suggesting bioaccumulation of these pesticides through the food chain.

Table: 3 Potential Impact of Agrochemicals on Human Health

Agrochemicals	**Potential Impact on Human Health**	**References**
Organophosphates (Pesticides)	Associated with neurological disorders, hormonal disruption, and increased risk of cancer	Gilden *et al*., 2010
Glyphosate (Herbicides)	Potentially linked with chronic kidney disease, reproductive issues, and cancer	Myers *et al*., 2016
Mancozeb (Fungicides)	Can cause thyroid disorders, and possess developmental and reproductive toxicity	Zhang *et al.*, 2018
Neonicotinoids (Insecticides)	Associated with neurodevelopmental disorders and cardiovascular diseases	Goulson, 2013
Anticoagulants (Rodenticides)	Can lead to hemorrhagic conditions and immune system disorders	Littin *et al.*, 2014

Exposure through Airborne Particles

Airborne exposure is another pathway of indirect exposure. A study by Abhilash *et al.* (2009) in the rice fields of West Bengal found that the spraying of pesticides contributed to ambient air pollution, potentially leading to respiratory and other health problems among both rural and urban populations.

The situation in India underscores the global challenges of both direct and indirect exposure to agrochemicals.

Direct Exposure in Indian Agricultural Workers

In India, agriculture employs a substantial portion of the population, exposing many to the direct risks of agrochemical use. These workers often lack appropriate protective equipment and education about safe handling practices. A study by Dasgupta *et al.* (2007) reported high incidence of symptoms related to pesticide exposure, such as headache, dizziness, and skin irritation, among farmers in West Bengal who frequently handled pesticides. This demonstrates the high risk of direct exposure and its health implications among agricultural workers in India.

Indirect Exposure through Food and Water Contamination

Indirect exposure through food and water is a significant concern for the general population in India. Shukla *et al.* (2018) found detectable levels of multiple pesticide residues in vegetables sold in markets across the country. In a study conducted by Sinha *et al.* (1997), a significant amount of organochlorine pesticide residues were detected in the breast milk of women from rural areas in Punjab, suggesting bioaccumulation of these pesticides through the food chain.

Exposure through Airborne Particles

Airborne exposure is another pathway of indirect exposure. A study by Sarkar *et al.* (2018) in the rice fields of West Bengal found that the spraying of pesticides contributed to ambient air pollution, potentially leading to respiratory and other health problems among both rural and urban populations.

Research on the Impacts of Agrochemicals on Human Health

Numerous studies have demonstrated potential health risks associated with agrochemical exposure. These include acute health effects, such as skin and eye irritation, headaches, dizziness, and nausea (Alp *et al.*, 2006). Long-term exposure has been linked with more serious health conditions, including various forms of cancer, neurological disorders, hormonal disruption, and reproductive health problems (Barouki *et al.*, 2012).

Role of Beneficial Microorganisms and Potential Impact of Agrochemicals

Beneficial microorganisms, especially those constituting the human gut microbiota, play a crucial role in human health. They aid in digestion, stimulate immune responses, and can even influence mood and behavior (Postler & Ghosh 2017). Agrochemicals, particularly pesticides like glyphosate, have been shown to alter the gut microbiota's composition (Motta, & Moran, 2020). This can disrupt the microbiota's normal functions, potentially contributing to a range of health conditions, from metabolic disorders like obesity and diabetes to mental health disorders (Rogers *et al*., 2016). The impact of agrochemicals on human health, whether direct or mediated through the alteration of beneficial microorganisms, is a significant concern. Further research is needed to fully understand these relationships and develop strategies to minimize potential harm.

Mitigation Strategies and Alternative Approaches

Best Management Practices

Best management practices (BMPs) that minimize the impact of agrochemicals on beneficial microorganisms involve careful application strategies and monitoring. For instance, applying pesticides only when necessary and in the recommended amounts can reduce microbial exposure (Bueno, 2022). Rotation of crops can also help manage pest populations and decrease dependence on pesticides (Hillocks, 2012). Additionally, regular soil testing can help tailor fertilizer application to actual crop needs, minimizing surplus nutrients that could potentially disrupt microbial communities.

Use of Organic Fertilizers

Organic fertilizers, such as compost, green manure, and vermicompost, are widely used in organic farming practices across India. These fertilizers not only replenish soil nutrients but also promote the growth and diversity of soil microorganisms, thereby improving soil structure and health (Pahalvi *et al.,* 2021). For example, a study conducted in Andhra Pradesh reported that the use of organic manures improved the population of beneficial nitrogen-fixing bacteria in the soil (Reddy et al., 2011).

Use of Organic Pesticides

The use of organic pesticides, such as neem-based pesticides and biopesticides derived from microorganisms (e.g., Bacillus thuringiensis), is also prevalent in India. Compared to synthetic pesticides, these organic alternatives have been found to have less harmful effects on non-target organisms, including beneficial soil microbes (Pino *et al*., 2019). For instance, a study conducted in Punjab found that biopesticides led to less disruption in soil microbial diversity compared to synthetic pesticides (Mishra *et al*., 2021).

Precision Agriculture

Precision agriculture leverages technology to optimize the use of agrochemicals, thereby reducing their environmental impact. This involves technologies like GPS, remote sensing, and variable rate technology to apply agrochemicals more accurately and efficiently (Zhang & Kovacs, 2012). By minimizing agrochemical use, precision agriculture can mitigate negative impacts on soil microbes and human health.

Use of Satellite and Drone Technologies

India's advancements in satellite and drone technologies have allowed for greater precision in agricultural practices. The use of satellite data has enabled precise soil and crop health monitoring, helping to tailor the application of agrochemicals according to the specific needs of the crops (Jat *et al*., 2019). Furthermore, drones are increasingly being used for precise application of fertilizers and pesticides, reducing the overall quantity of agrochemicals used and their potential harmful effects (Kaur *et al*., 2020).

Implementation of Sensor-based Irrigation Systems

Sensor-based irrigation systems have also been developed to optimize water and fertilizer use. These systems monitor soil moisture levels in real-time and provide precise irrigation only when required, reducing water wastage and leaching of fertilizers into the environment (Kaur *et al*., 2021).

Role of Digital Farming Platforms

Several digital farming platforms have been developed in India, like CropIn, providing real-time advisory services to farmers about pest/disease outbreaks, weather forecasts, and optimal fertilization schedules. These platforms aid in precision farming by enabling timely and judicious use of agrochemicals, thereby mitigating their impact on soil microorganisms and the environment (Rao *et al*., 2020).

Genetically Modified Crops

Use of Bt Cotton in India

India is the world's largest producer of cotton, and Bt cotton - genetically modified to produce Bacillus thuringiensis toxin that kills bollworm, a common pest - is widely grown. Since the introduction of Bt cotton in 2002, there has been a significant reduction in the use of chemical pesticides in cotton cultivation, thus potentially reducing their impact on soil microorganisms and human health (Kouser & Qaim, 2011).

Impact on Soil Microbes

The potential effects of GM crops, like Bt cotton, on soil microbes are not fully understood. Some studies in India have reported minor changes in soil microbial diversity with Bt cotton cultivation, while others have found no significant difference when compared with conventional cotton (Kumar et al., 2018; Singh et al., 2011). Therefore, it underscores the need for long-term, comprehensive studies to understand better the impacts of GM crops on soil microbial communities.

Genetically Modified Mustard

Another case is the development of GM mustard (DMH-11), which was engineered for herbicide tolerance and higher yield. Despite the potential benefits in reducing herbicide use, it has not yet been approved for commercial cultivation due to environmental and food safety concerns (Sharma, 2020).

Current Gaps in Knowledge and Future Research Opportunities

While the body of research on the impacts of agrochemicals on soil microbes and human health is growing, many gaps still exist. The individual effects of different types of agrochemicals on various microbial species are not completely understood (Harrier *et al*., 2004). Additionally, the majority of research has focused on short-term, immediate effects of agrochemicals, while long-term impacts on microbial communities and their functions remain underexplored (Guedes *et al*., 2022). The mechanisms through which changes in soil microbiota due to agrochemical exposure might impact human health, particularly through pathways involving the human microbiome, are still largely speculative and require more rigorous scientific investigation (Hooks *et al*, 2019).

Suggestions for Future Research

Potential future research topics could include long-term field studies to understand the chronic effects of different agrochemicals on soil microbiota, including their impact on microbial community structure, function, and resilience. Additionally, more research is needed to understand the indirect effects of agrochemicals on human health, particularly the mechanisms by which alterations in soil and gut microbiota might contribute to diseases. Experimental studies exploring the potential of alternative farming practices, such as organic farming, permaculture, and the use of biopesticides, in mitigating the adverse effects of agrochemicals on soil microbes and human health could provide useful insights.

Need for Integrated, Interdisciplinary Research

Given the complex interplay between agrochemicals, microorganisms, and human health, an integrated, interdisciplinary approach is crucial to fully understand this nexus. Such an approach would involve collaboration between soil scientists, microbiologists, toxicologists, public health researchers, and agricultural experts. Developing this integrative knowledge base is essential for the development of sustainable agricultural practices that safeguard soil health, human health, and overall ecosystem resilience (Yang *et al*., 2020).

Conclusion

Agrochemicals, though vital for modern agriculture, pose significant challenges to soil microbial health and human wellbeing. Their adverse effects, as evident from various studies, necessitate the adoption of alternative agricultural practices, such as organic farming, precision agriculture, and the use of genetically modified crops. Given the complexity of these issues, significant research gaps remain. Future studies should adopt an integrated, interdisciplinary approach to fully understand the interplay between agrochemicals, soil microorganisms, and human health, thereby paving the way for sustainable, health-conscious agriculture.

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