Journal of Toxicology 2024, 2(1), 250.
https://doi.org/10.59400/jt.v2i1.250

Review

Toxicity of agrochemicals: Impact on environment and human health

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CITATION

Anjaria P, Vaghela S. Toxicity of agrochemicals: Impact on environment and human health. Journal of Toxicology. 2024; 2(1): 250. https://doi.org/10.59400/jt.v2i1.250

ARTICLE INFO

Received: 1 December 2023
Accepted: 12 January 2024
Available online: 18 February 2024

Abstract: Agrochemicals, while essential for increasing agricultural yields and pest control, have unintended consequences. They contaminate soil and water, disrupting ecosystems, reducing biodiversity, and threatening aquatic life. Furthermore, agrochemicals harm non-target organisms, disrupting ecological balance. On the human health front, farmworkers and pesticide applicators face acute poisoning risks, with symptoms ranging from discomfort to severe illness or death. Chronic health effects include links to cancer, neurological disorders, and reproductive problems, raising concerns about food safety and worker well-being. Addressing agrochemical toxicity requires a multifaceted approach. Governments must enforce strict regulations to minimize environmental contamination and ensure safe handling practices. The agricultural industry can adopt sustainable methods like integrated pest management (IPM) and organic farming to reduce reliance on agrochemicals. Innovations such as precision agriculture, biological pest control, nanotechnology, and artificial intelligence for early risk detection are essential. Collaboration among stakeholders is critical for a more sustainable and environmentally friendly agriculture sector, involving regulatory measures like maximum residue limits (MRLs) and sustainable practices like IPM and organic farming. In summary, this review highlights the urgent need to address agrochemical toxicity holistically, balancing agricultural productivity with environmental and health concerns to ensure a sustainable future for agriculture and the planet.

Keywords: acute poisoning; agrochemicals; artificial intelligence; public health; sustainable agriculture

1. Introduction

The toxicity of agrochemicals has profound implications for both the environment and human health. In agriculture, these chemicals are used to boost crop yields and protect against pests, but their unintended consequences are increasingly evident. Agrochemicals can contaminate soil and water, disrupting ecosystems and reducing biodiversity. Soil contamination can lead to long-term fertility issues, while water pollution threatens aquatic life and the quality of drinking water sources. Furthermore, the harm caused to non-target organisms, such as beneficial insects and birds, highlights the intricate interconnections within ecosystems that are disrupted by the use of agrochemicals.

On the human health front, the impact of agrochemicals is equally concerning. Acute poisoning is a risk for farmworkers and pesticide applicators who handle these chemicals, with symptoms ranging from mild discomfort to severe illness or even death [1]. More insidious are the chronic health effects associated with long-term exposure to agrochemical residues. These include links to cancer, neurological disorders, and reproductive problems, raising concerns about the safety of the food we consume and the well-being of those working in agriculture [2–4].

Addressing the toxicity of agrochemicals requires a multifaceted approach. Governments must enforce strict regulations to minimize environmental contamination and ensure safe handling practices. Meanwhile, the agricultural industry can adopt sustainable methods like integrated pest management (IPM) and organic farming to reduce reliance on these chemicals. It is crucial to strike a balance between agricultural productivity and environmental and human health concerns to build a sustainable future for agriculture and our planet.

2. Environmental impact

Environmental concerns require a shift towards sustainable agricultural practices. Integrated pest management (IPM), organic farming, crop rotation, and reduced chemical usage are some strategies that can mitigate the adverse effects of agrochemicals on the environment while maintaining food production. Additionally, improved education and awareness among farmers about responsible agrochemical use are essential steps toward reducing their environmental footprint.

2.1. Soil contamination

Loss of soil fertility: Agrochemicals, particularly synthetic fertilizers, can lead to soil degradation. Excessive use of fertilizers can disrupt the natural nutrient balance in the soil. Over time, this can lead to nutrient imbalances, making the soil less fertile and reducing crop yields [5].

Microbial disruption: Soil is home to a diverse ecosystem of microorganisms that play a vital role in nutrient cycling and soil health. Agrochemicals, especially pesticides, can harm beneficial soil microorganisms, disrupting these vital processes [6].

Persistence: Some agrochemicals, such as certain herbicides, can persist in the soil for extended periods. This persistence can lead to long-term contamination and potential harm to future crops [7].

2.2. Water pollution

Runoff: When it rains or when fields are irrigated, agrochemicals on the soil's surface can be washed into nearby water bodies. This runoff carries pesticides, herbicides, and fertilizers into rivers, lakes, and streams [8].

Groundwater contamination: Agrochemicals can leach through the soil and contaminate groundwater, which serves as a source of drinking water for many communities. Prolonged exposure to contaminated groundwater can have serious health consequences [9].

Algal blooms: Fertilizer runoff containing excess nutrients like nitrogen and phosphorus can trigger algal blooms in water bodies. These blooms can deplete oxygen levels in the water, harming aquatic life and creating "dead zones" [10].

2.3. Harm to non-target organisms

Insecticides and pollinators: Insecticides, designed to target pest insects, can inadvertently harm beneficial insects like bees and butterflies, which are essential for pollinating crops. This can disrupt the natural balance in ecosystems and reduce crop yields [11].

Birds and aquatic life: The contamination of water bodies with pesticides can harm aquatic organisms, including fish and amphibians. Birds that feed on contaminated aquatic life can also suffer adverse effects.

2.4. Residue and resistance

Food residue: Agrochemical residues can remain on harvested crops. Consumers may unknowingly ingest these residues, potentially leading to health risks. This is why monitoring and regulating maximum residue limits (MRLs) on food items is crucial.

Pest and weed resistance: Prolonged and widespread use of agrochemicals can lead to the development of resistance in pest insects and weeds. This means that over time, higher concentrations or different chemicals may be needed to achieve the same level of pest control, increasing the overall environmental impact.

3. Human health impact

The human health impact of agrochemicals necessitates stringent safety regulations, proper training, and the use of protective equipment for those handling these chemicals. Additionally, promoting alternative, less toxic agricultural practices, such as organic farming and integrated pest management, can reduce the reliance on hazardous agrochemicals. Monitoring and regulation of agrochemical residue levels on food items are crucial to safeguard consumer health. Overall, a holistic approach is essential to protect both the environment and human health from the adverse effects of agrochemicals.

3.1. Acute poisoning

Farmworker exposure: Farmworkers and pesticide applicators are at the highest risk of acute poisoning. They work directly with agrochemicals and can be exposed to high concentrations. Symptoms of acute poisoning can range from mild skin or eye irritation to more severe effects like nausea, vomiting, diarrhea, dizziness, and, in extreme cases, respiratory distress or death.

Accidental exposure: Accidental exposure can occur through mishandling of agrochemicals or the lack of proper protective equipment. Inadequate training and safety measures can increase the risk of such incidents.

3.2. Chronic health effects

Cancer: Some agrochemicals, such as certain pesticides and herbicides, have been classified as known or suspected carcinogens. Long-term exposure to these substances, even at low levels, can increase the risk of cancer among agricultural workers [2].

Neurological disorders: Exposure to certain agrochemicals has been linked to neurological disorders. Organophosphate pesticides, for example, have been associated with cognitive and motor deficits, particularly in children [3].

Reproductive problems: Some agrochemicals are endocrine disruptors, which means they can interfere with the hormonal systems of humans. This can lead to reproductive problems, including reduced fertility and developmental issues in children [4].

3.3. Residue on food

Consumer exposure: Residues of agrochemicals can remain on food items after harvesting. Consumers who regularly consume these residues may face long-term health risks, especially vulnerable populations such as children, pregnant women, and individuals with compromised immune systems.

Children's health: Children are particularly susceptible to the effects of agrochemicals due to their developing bodies and higher relative food consumption. Prenatal exposure can also have lifelong implications.

3.4. Occupational risks

Farmworkers and their families: Agricultural workers often bring home pesticide residues on their clothing and bodies, which can pose risks to their families. This is known as "take-home exposure" and can affect children and other household members.

Lack of awareness: In many agricultural communities, there may be a lack of awareness about the risks associated with agrochemical exposure. This can lead to inadequate protection and safety measures among farmworkers.

3.5. Psychosocial impact

Stress and mental health: The awareness of the potential health risks associated with agrochemical exposure can lead to stress and mental health issues among agricultural workers and their families. Fear of exposure and its consequences can create a significant psychological burden.

4. Innovations and initiatives to tackle adverse effects of agrochemicals on human and environmental health

4.1. Precision agriculture (PA)

Precision agriculture involves the use of advanced technology to optimize farming practices. GPS-guided machinery, drones, and sensor networks help farmers make data-driven decisions regarding the application of agrochemicals. By precisely targeting areas of the field that require fertilizers, pesticides, or herbicides, farmers can minimize overuse, reduce costs, and limit the environmental impact of these chemicals. PA also allows for real-time monitoring of crop health, enabling early detection of issues and prompt action, further reducing the need for chemical interventions [12].

4.2. Biological pest control

Biological pest control utilizes natural predators, parasites, and pathogens to manage pest populations. Beneficial insects like ladybugs and parasitoid wasps, as well as microorganisms such as nematodes and fungi, are used to control pests without resorting to synthetic pesticides. This approach is environmentally friendly and helps maintain ecological balance in agricultural ecosystems [13].

4.3. Integrated pest management (IPM)

IPM is a holistic approach that combines multiple strategies to manage pests effectively. Farmers monitor pest populations, use biological controls, implement crop rotation, and only resort to chemical pesticides when necessary. By minimizing chemical use and promoting natural pest control methods, IPM reduces the ecological footprint of agriculture [14].

4.4. Nanoencapsulation

Nanoencapsulation involves enclosing agrochemicals in tiny capsules to improve their delivery and release. This technology enhances the efficiency of agrochemicals, reducing the quantity needed while prolonging their effects. This results in reduced environmental contamination and fewer health risks for workers handling these chemicals [15].

4.5. Biodegradable and reduced-risk pesticides

Researchers are developing agrochemicals that break down more quickly in the environment, reducing their persistence and potential harm. These reduced-risk pesticides have lower toxicity to non-target organisms, including humans, wildlife, and beneficial insects. They are designed to be less harmful to ecosystems while still effectively controlling pests.

4.6. Gene editing

Gene editing techniques, such as CRISPR/Cas9, are used to develop crops with enhanced resistance to pests and diseases. By modifying the plant’s genetic makeup, farmers can reduce their reliance on chemical pesticides. This innovation offers long-term solutions to pest management while minimizing environmental impacts [16].

4.7. Sustainable farming practices

Sustainable farming practices, such as cover cropping, reduced tillage, and organic farming, focus on reducing agrochemical use. Cover crops enhance soil health and reduce the need for synthetic fertilizers, while reduced tillage prevents soil erosion and retains moisture. Organic farming avoids synthetic chemicals altogether, relying on natural alternatives.

4.8. Remote sensing and data analytics

Remote sensing technologies like satellites and drones provide farmers with valuable data on crop health and pest infestations. Data analytics and machine learning algorithms help interpret this information in real time, allowing farmers to make timely decisions about agrochemical applications. Early detection and targeted responses minimize chemical use and its associated risks.

4.9. Blockchain and transparency

Blockchain technology is used to create transparent supply chains in agriculture. Consumers can trace the origin of their food products and verify the use of sustainable and responsible farming practices. This transparency incentivizes farmers to reduce chemical use, adopt eco-friendly practices, and meet the growing demand for environmentally conscious food production [17].

5. Application of artificial intelligence

Artificial intelligence (AI) stands as one of the most transformative and impactful technological advancements of our era, encompassing a wide spectrum of capabilities that simulate human intelligence. At its core, AI involves the creation of machines, software, and systems that can think, reason, learn, and adapt to various situations, mirroring human cognitive functions. It enables these entities to process large volumes of data, identify patterns, and make decisions based on the insights gathered. One of the fundamental branches of AI is machine learning, which empowers systems to improve their performance over time through exposure to data. Machine learning algorithms, inspired by the neural networks of the human brain, can learn from examples and experiences, iteratively refining their responses. This capability has led to breakthroughs in diverse fields, from medical diagnoses and autonomous vehicles to natural language processing and recommendation systems.

AI's impact is not limited to just machine learning; it encompasses a broader range of techniques. For instance, natural language processing (NLP) enables computers to understand, interpret, and generate human language. This has given rise to virtual assistants and chatbots like ChatGPT that can converse with users in a human-like manner, making interactions with technology more intuitive [18]. Artificial intelligence harnesses data patterns and predictive models to foresee potential disease outbreaks, enabling proactive measures and rapid responses to mitigate their impact on public health. By analyzing diverse data sources, AI aids in early detection and prediction, revolutionizing disease surveillance and prevention strategies [19]. Through the integration of artificial intelligence, digital twins in healthcare, including gene sequencing, facilitate the development of virtual genetic models that mimic individual patients, revolutionizing our comprehension of genetic information and propelling personalized medicine with precisely customized interventions [20].

5.1. Early detection of health risks

AI-driven early detection of health risks associated with agrochemical exposure is a critical component of ensuring the safety and well-being of farmworkers and nearby communities. AI leverages data from various sources, including weather patterns, soil conditions, and historical pesticide usage, to create predictive models. These models can identify high-risk areas where pesticide drift or contamination is likely to occur. By analyzing wind patterns, temperature, and crop characteristics, AI can forecast when and where agrochemicals may disperse beyond their intended target. This early warning system enables farmers and regulatory agencies to take preemptive measures, such as adjusting application methods or temporarily halting operations, to protect human health.

Additionally, AI can integrate real-time data from sensors placed in fields and on farm equipment. These sensors can monitor factors like pesticide concentration in the air and soil, allowing for immediate alerts if exposure levels exceed safe thresholds. Farmworkers can be equipped with wearable devices that continuously track their exposure levels, providing them with warnings and safety recommendations in real time. This proactive approach to risk management reduces the likelihood of acute and chronic health issues resulting from agrochemical exposure.

Furthermore, AI systems can analyze the historical health data of farmworkers in relation to their work environments. By identifying correlations between specific chemical exposures and health outcomes, AI can assist in establishing evidence-based regulations and safety guidelines. This ensures that policies are informed by data, leading to more effective protection of human health in agriculture.

5.2. Pesticide exposure monitoring

AI-powered pesticide exposure monitoring is a crucial tool in safeguarding the health of farmworkers who handle and apply agrochemicals. AI integrates data from a variety of sources to provide comprehensive and real-time insights into exposure levels. For instance, wearable devices equipped with sensors can continuously measure the concentration of airborne pesticides, as well as assess skin contact. These wearables transmit data to AI algorithms, which analyze the information against safety thresholds. By applying machine learning techniques, AI can provide farmworkers with personalized recommendations and alerts based on their unique exposure profiles. For example, if a worker’s wearable device detects a spike in pesticide concentration, AI can issue an immediate warning and suggest specific protective measures, such as wearing additional protective gear or moving to a safer area. This real-time feedback empowers farmworkers to make informed decisions to mitigate their exposure.

Moreover, AI-driven exposure monitoring systems can collect and store data over time, creating a comprehensive record of individual exposure histories. This data is invaluable for occupational health assessments, enabling healthcare professionals to evaluate the long-term effects of agrochemical exposure on farmworkers. It also aids in identifying trends and patterns related to exposure, which can inform the development of targeted interventions and safety protocols. In addition to protecting farmworkers, AI-based pesticide exposure monitoring contributes to the overall reduction of chemical risks in agriculture. By pinpointing areas and practices associated with high exposure levels, farmers and regulatory authorities can take measures to optimize application techniques, adopt safer alternatives, or implement buffer zones to minimize the risk to nearby communities and the environment.

6. Regulatory measures and sustainable practices

Balancing the need for agricultural productivity with environmental and health concerns is a complex challenge. Regulatory measures ensure the safe use of agrochemicals, while sustainable practices aim to reduce their overall impact. Collaboration between governments, farmers, researchers, and consumers is crucial to achieving a more sustainable and environmentally friendly agriculture sector.

6.1. Regulatory measures

Maximum residue limits (MRLs): Governments around the world establish MRLs for pesticides and other agrochemical residues on food products. These limits define the maximum allowable concentration of residues that can remain on or in food items. Regular monitoring and enforcement of MRLs are critical to ensure food safety.

Pesticide registration and approval: Agrochemicals must go through a rigorous registration and approval process before they can be sold and used. This process evaluates the safety and efficacy of these chemicals, taking into account potential risks to the environment, human health, and non-target organisms.

Labeling and safety data sheets: Agrochemical products come with detailed labels and safety data sheets that provide information on proper handling, application, storage, and disposal. These documents also outline safety precautions to minimize risks during use.

Training and certification: Many countries require individuals who handle and apply agrochemicals to undergo training and certification. This training covers safe handling practices, protective equipment usage, and the responsible use of these chemicals.

Buffer zones and restricted application: Regulations may mandate buffer zones around treated fields to reduce the risk of drift and contamination of nearby areas. Additionally, some chemicals may have restrictions on their application during certain times or under specific weather conditions to minimize environmental impact.

6.2. Sustainable practices

Integrated pest management (IPM): IPM is an approach that combines biological, cultural, physical, and chemical strategies to manage pests and diseases. It emphasizes the judicious use of agrochemicals as a last resort after non-chemical methods have been exhausted. IPM aims to minimize the environmental impact while maintaining crop productivity.

Organic farming: Organic farming avoids synthetic agrochemicals and relies on natural alternatives. It prioritizes soil health, crop rotation, and the use of organic fertilizers and pesticides that have a lower environmental impact. Organic certification ensures adherence to these practices.

Crop rotation and diversification: Crop rotation helps break the cycle of pests and diseases, reducing the need for chemical interventions. Diversifying crops in a rotation can also improve soil health and reduce the risk of soil degradation.

Biological control: Beneficial insects, nematodes, and microorganisms can be used to control pest populations. This biological control method is environmentally friendly and minimizes the use of chemical pesticides.

Precision agriculture: Precision agriculture employs technology like GPS-guided tractors and drones to optimize the use of agrochemicals. By targeting specific areas with pest or nutrient issues, farmers can reduce overall chemical usage and minimize environmental impact.

Cover crops and conservation practices: Planting cover crops and adopting conservation tillage practices can reduce soil erosion, improve soil health, and minimize the need for chemical fertilizers and herbicides.

Research and innovation: Continued research into alternative pest control methods, the development of less toxic agrochemicals, and the promotion of sustainable farming practices are essential for reducing the environmental and health impact of agriculture.

Conflict of interest: The authors declare no conflict of interest.

References

1. Sekhotha M, Monyeki K, Sibuyi M. Exposure to Agrochemicals and Cardiovascular Disease: A Review. International Journal of Environmental Research and Public Health. 2016; 13(2): 229. doi: 10.3390/ijerph13020229
2. Anaduaka EG, Uchendu NO, Asomadu RO, et al. Widespread use of toxic agrochemicals and pesticides for agricultural products storage in Africa and developing countries: Possible panacea for ecotoxicology and health implications. Heliyon. 2023; 9(4): e15173. doi: 10.1016/j.heliyon.2023.e15173
3. Rossetti MF, Stoker C, Ramos JG. Agrochemicals and neurogenesis. Molecular and Cellular Endocrinology. 2020; 510: 110820. doi: 10.1016/j.mce.2020.110820
4. Said M. An Overview of Impact of Agrochemicals on Human Health and Natural Environment. Scientific Research Communications. 2023; 3(2): 32-39. doi: 10.52460/src.2023.009
5. Hossain ME, Shahruk , Hossain, SA. Chemical Fertilizers and Pesticides: Impacts on Soil Degradation, Groundwater, and Human Health in Bangladesh. 2022. pp. 63–92. doi: 10.1007/978-3-030-95542-7_4
6. Malik Z, Ahmad M, Abassi GH, et al. Agrochemicals and Soil Microbes: Interaction for Soil Health. 2017. pp. 139–152. doi: 10.1007/978-3-319-47744-2_11
7. Mandal A, Sarkar B, Mandal S, et al. Impact of agrochemicals on soil health. Agrochemicals Detection, Treatment and Remediation. Published online 2020: 161-187. doi: 10.1016/b978-0-08-103017-2.00007-6
8. Kaur T, Sinha AK. Pesticides in Agricultural Run Offs Affecting Water Resources: A Study of Punjab (India). Agricultural Sciences. 2019; 10(10): 1381-1395. doi: 10.4236/as.2019.1010101
9. Syafrudin M, Kristanti RA, Yuniarto A, et al. Pesticides in Drinking Water—A Review. International Journal of Environmental Research and Public Health. 2021; 18(2): 468. doi: 10.3390/ijerph18020468
10. Bailey A, Meyer L, Pettingell N, et al. Agricultural practices contributing to aquatic dead zones. In: Ecological and Practical Applications for Sustainable Agriculture. Springer Singapore. 2020. pp. 373–393. doi: 10.1007/978-981-15-3372-3_17
11. Upholt WM, Kraybill HF. Ecological effects of pesticides. Annals of the New York Academy of Sciences. 1969; 160(1): 55-60. doi: 10.1111/j.1749-6632.1969.tb15823.x
12. Nicolopoulou-Stamati P, Maipas S, Kotampasi C, et al. Chemical Pesticides and Human Health: The Urgent Need for a New Concept in Agriculture. Frontiers in Public Health. 2016; 4. doi: 10.3389/fpubh.2016.00148
13. Popp J, Pető K, Nagy J. Pesticide productivity and food security. A review. Agronomy for Sustainable Development. 2012; 33(1): 243-255. doi: 10.1007/s13593-012-0105-x
14. Singh A, Dhiman N, Kar AK, et al. Advances in controlled release pesticide formulations: Prospects to safer integrated pest management and sustainable agriculture. Journal of Hazardous Materials. 2020; 385: 121525. doi: 10.1016/j.jhazmat.2019.121525
15. Nuruzzaman Md, Rahman MM, Liu Y, et al. Nanoencapsulation, Nano-guard for Pesticides: A New Window for Safe Application. Journal of Agricultural and Food Chemistry. 2016; 64(7): 1447-1483. doi: 10.1021/acs.jafc.5b05214
16. Menz J, Modrzejewski D, Hartung F, et al. Genome Edited Crops Touch the Market: A View on the Global Development and Regulatory Environment. Frontiers in Plant Science. 2020; 11. doi: 10.3389/fpls.2020.586027
17. Jadav NK, Rathod T, Gupta R, et al. Blockchain and artificial intelligence-empowered smart agriculture framework for

maximizing human life expectancy. Computers and Electrical Engineering. 2023; 105: 108486. doi: 10.1016/j.compeleceng.2022.108486

18. Soni M, Anjaria P, Koringa P. The revolutionary impact of chatGPT: advances in biomedicine and redefining healthcare with large language models. Future Medicine AI. Published online August 17, 2023. doi: 10.2217/fmai-2023-0011
19. Anjaria P, Asediya V, Bhavsar P, et al. Artificial Intelligence in Public Health: Revolutionizing Epidemiological Surveillance for Pandemic Preparedness and Equitable Vaccine Access. Vaccines. 2023; 11(7): 1154. doi: 10.3390/vaccines11071154
20. Asediya V, Anjaria P. Quantum leap: is the conflux of artificial intelligence, personalized medicine, nutrigenetics and nutrigenomics the path to optimal health? Epigenomics. 2023; 15(7): 397-400. doi: 10.2217/epi-2023-0084