EFFECTS OF PESTICIDES ON SOIL ORGANIC MATTER: A MINI-REVIEW

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Abstract

Pesticides are natural synthetic chemical substances used extensively in agriculture to control of pests such as insects, weeds, and plant diseases. These chemicals are categorized based on the some type of pest. Some of them target including herbicides (for herbs), insecticides (against insects), fungicides (against fungal diseases). The application of pesticides provides several significant benefits, including improved food quality and crop yields, as well as the reduction of pest-borne diseases. Despite these advantages, the widespread use of pesticides has raised concerns regarding their environmental impact, particularly with respect to water contamination and the long-term health of ecosystems (Jablonowski et al., 2011; Geissen et al., 2015; Schlappi et al., 2020; Rasool et al., 2022). The fertilities and behaviors of all pesticides in soil are influenced by various environmental and climatic factors such as temperature, humidity, precipitation, and key soil properties. Among these, soil texture and organic matter content are the most critical physicochemical factors affecting pesticide retention, degradation, and mobility (Flury, 1996; Gavrilescu, 2005; Sharma et al., 2012). Soil organic matter (SOM) plays a pivotal role in the retention and adsorption of pesticides within the soil, particularly in the root zone where pesticide absorption by plants occurs. Practices aimed at enhancing soil organic matter content, such as the incorporation of cover crops, or the addition of organic amendments like compost and manure, have been shown to significantly improve soil health. These practices increase the soil's capacity to retain both water and dissolved pesticides, making them more readily available for plant uptake and microbial degradation. As a result, the risk of pesticide leaching into groundwater is minimized, thus promoting more sustainable agricultural practices (Flury, 1996; Gavrilescu, 2005; Celis et al., 2008). However, the use of pesticides is not without its challenges. While they offer substantial benefits in pest management, their impact on soil organic matter and soil microbial communities is of growing concern. The interaction between pesticides and soil health, particularly the mechanisms through which they influence soil organic matter dynamics, requires further investigation. Understanding these interactions will be critical in developing soil management practices that mitigate the adverse effects of pesticide use while ensuring the continued efficacy of pest control methods (Makszim and Soós, 2025). In conclusion, while pesticides are indispensable for modern agriculture, their environmental implications, particularly in relation to soil health and organic matter dynamics, need careful consideration. Future research should focus on identifying practices that balance effective pest control with sustainable soil management, ensuring long-term agricultural productivity and environmental sustainability.

Key Words: Environmental Conditions, Pesticides, Soil Organic Matter, Sustainability

Introduction

Soil organic matter (SOM) is an integral component of soil ecosystems, influencing key soil functions such as nutrient cycling, water retention, soil structure, and microbial diversity (Schjønning et al., 2018). SOM is considered a major determinant of soil fertility and plays a critical role in carbon sequestration, thus impacting global climate regulation (Friedlingstein et al., 1995; Kicklighter et al, 1999). The decomposition of organic materials, driven by a wide variety of soil microorganisms, sustains SOM dynamics and supports plant growth by providing

essential nutrients (Cotrufo and Lavallee, 2022). However, the application of pesticides both synthetic and biopesticides in agricultural practices has raised significant concerns about their potential to disrupt soil ecological processes, particularly organic matter dynamics (Zhou et al., 2025). Pesticides, which are routinely applied to control pests, weeds, and diseases, can affect SOM by altering microbial populations, enzyme activities, and nutrient cycling processes (Daunoras et al., 2024). Recent findings suggest that the combined use of synthetic pesticides and the absence of organic amendments accelerates microbial imbalance and suppresses enzymatic degradation of complex organic residues (Csabai et al. 2021, Csabai et al., 2022; Kosztyuné Krajnyák et al. 2024). The present review aims to provide an in-depth analysis of how pesticides influence SOM decomposition, microbial communities, and overall soil fertility, synthesizing findings from recent studies to highlight the broader environmental implications. Field experiments with fermented poultry manure and compost show promise in counteracting these negative effects, restoring microbial biodiversity and enhancing SOM turnover rates in degraded soils (Csabai et al., 2022).

Pesticide Types and Their Mechanisms

Pesticides can be broadly categorized into herbicides, insecticides, and fungicides. Each type possesses unique chemical properties and mechanisms of action, which can influence their interaction with soil organic matter.

Herbicides: These chemicals are designed to inhibit the growth of unwanted plants but can also significantly alter soil microbial communities. Glyphosate, for instance, is the most widely used herbicide and has been shown to reduce microbial diversity and affect the breakdown of organic matter (Kremer & Li, 2003; Galarneau et al., 2018; Van Bruggen et al., 2018). Studies indicate that glyphosate can bind to soil particles, affecting nutrient availability and leading to changes in microbial community composition (Davis et al., 2018). By applying glyphosate on stubble fields, the level of infestation with perennial weeds difficult to control using herbicides specific to individual crops is reduced. (Mondici, 2020).

Insecticides: Insecticides target specific pests but can adversely affect non-target soil organisms. Neonicotinoids, a class of systemic insecticides, have been linked to decreased soil microbial biomass and altered organic matter decomposition rates (Goulson, 2013; Rundlöf et al., 2015; Sgolastra et al., 2019). Research has shown that neonicotinoids can persist in the soil and impact microbial communities for extended periods, leading to long-term ecological consequences (Biondi et al., 2019).

Fungicides: Fungicides are used to control fungal pathogens but can also disrupt beneficial soil fungi essential for organic matter decomposition. The application of fungicides such as azoles and strobilurins may inhibit mycorrhizal fungi, which play a crucial role in nutrient cycling and soil structure maintenance (Miller & Jastrow, 1990; Bórdalo et al., 2016; Alguacil et al., 2020). This disruption can lead to reduced organic matter breakdown and nutrient availability for plants.

Impact on Soil Organic Matter Dynamics

The application of pesticides can lead to several changes in soil organic matter dynamics:

Decomposition Rates: Pesticides can slow down the decomposition of organic matter by affecting microbial communities responsible for breaking down organic materials. A decrease in microbial activity can result in the accumulation of organic residues, altering the soil's physical and chemical properties (Pérez et al., 2015; Rousk et al., 2016; Doran & Parkin, 1994). Furthermore, studies have indicated that certain herbicides can reduce the activity of soil enzymes

involved in organic matter degradation (Sinsabaugh et al., 2008).This has led to increased interest in soil-friendly alternatives such as microbial inoculants and organic amendments, which may support nutrient cycling even under pollutant stress (Suryatmana et al., 2024).

Microbial Diversity: The use of pesticides often leads to a reduction in microbial diversity, which is critical for maintaining soil health. This decline can impair the soil's ability to decompose organic matter effectively and disrupt the balance of soil nutrient cycles (Nannipieri et al., 2018; Jangid et al., 2011; Fierer et al., 2009). Reduced microbial diversity can also make soils more susceptible to diseases and other stressors (González et al., 2015).

Soil Structure: Changes in microbial communities caused by pesticide application can negatively impact soil aggregation and structure. Healthy soil organic matter contributes to soil aggregation, enhancing water retention and aeration. Pesticide-induced alterations in microbial populations can compromise these beneficial properties (Kumar et al., 2018; Zaller et al., 2014; Vance et al., 1987). Research has shown that reduced microbial diversity can lead to decreased soil stability and increased erosion risk (Mikha et al., 2006).

Conclusion

The effects of pesticides on soil organic matter are complex and multifaceted. While pesticides play a crucial role in modern agriculture, their impact on soil health and sustainability cannot be overlooked. Continued research is needed to better understand these interactions and to develop sustainable agricultural practices that protect soil organic matter and overall soil health. Implementing integrated pest management strategies and promoting the use of organic or less harmful pesticide alternatives may mitigate the adverse effects on soil ecosystems.

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