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Influence of farm pesticides on ants and beneficial microorganisms

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Abstract
Modern agriculture relies heavily on chemical pesticides to control pests and improve crop yield, but their continuous application may unintentionally disturb soil -based ecological systems. Ants are important bio-indicators of soil quality due to their role in soil aeration, organic matter breakdown, and regulation of other invertebrates, while soil microorganisms drive essential biochemical processes such as nutrient cycling and decomposition. This study examines how agricultural pesticide use influences ant community dynamics and soil microbial diversity in cultivated fields. Comparative field investigations were carried out in pesticide-treated farmlands and nearby non-treated sites. Ant populations were analysed for species composition, richness, and dominance patterns, and soil samples were assessed for microbial diversity and biological activity. The findings reveal noticeable changes in ant community structure, including reduced species richness and increased dominance of a few tolerant species in pesticide-exposed areas. Similarly, soil microbial diversity showed signs of decline, indicating stress on soil biological functioning. These results suggest that long-term pesticide use can negatively affect below-ground biodiversity and ecosystem stability. The study underlines the importance of adopting environmentally responsible pest management strategies to protect beneficial soil organisms and promote sustainable agricultural practices.

Keywords: Agricultural pesticides, ant community structure, soil microbial diversity, agro-ecosystem, non-target organisms, soil biodiversity, sustainable agriculture, ecosystem health

Introduction
Agricultural modernization has intensified chemical pesticide application across global farmlands, drastically affecting soil biota and ecological processes. Ants and microorganisms play essential roles in nutrient mineralization, litter decomposition, pest suppression, and soil structure maintenance. According to ecological studies, ants serve as sensitive bioindicators of soil disturbance due to their nesting behaviour and trophic interactions (Hölldobler & Wilson, 1990) [6]. Similarly, soil microbes are responsible for nearly 90% of nutrient transformations in terrestrial ecosystems (Paul, 2014) [10].

Pesticides enter soils through direct application, foliar wash-off, irrigation runoff, and crop residue deposition. Studies show that persistent compounds such as organophosphates, organochlorines, and neonicotinoids accumulate in soil and disrupt biological functions (Goulson, 2013) [5]. Because ants and microorganisms interact closely within the soil matrix, any disturbance in microbial composition influences ant nesting and food availability, thereby reshaping ant community structure. By analysing nest construction as both a biological necessity and an evolutionary adaptation, this study emphasizes the role of environmental pressures, soil type, and vegetation, climate, and predator-prey interactions in shaping nest architecture. The discussion also explores how nest-building contributes to ecosystem engineering, soil modification, and species coexistence. Finally, the paper identifies gaps in current research and outlines future directions for integrative studies linking ant ethology, ecology, and biomimicry. Ants quickly established trails to food sources, with distinct pheromone paths forming within 10-15 minutes of discovery. As the number of ants increased, the trail became more defined, demonstrating a positive feedback loop where each returning ant reinforced the path. (Sahu *et al.*, 2025) [13, 14]

Thus, this research examines how agricultural pesticide exposure alters (1) ant community structure and (2) soil microbial diversity, using ecological observations, previous scientific evidence, and current theoretical frameworks.

Literature Review
1. Ants as Soil Bioindicators
Ants respond rapidly to environmental perturbations due to their strong dependence on soil conditions and resource availability. For example, *Camponotus* and *Pheidole* species decline significantly in pesticide-exposed fields (Lopes & Vasconcelos, 2011) [9]. Ant colony collapse leads to reduced soil aeration and nutrient cycling.

Research reveals that ant communities change when exposed to pyrethroids, organophosphates, and neonicotinoids, which affect foraging ability, navigation, and colony reproduction (Stanley, 2017) [12].

2. Soil Microbial Diversity and Sensitivity to Pesticides
Soil microbes—bacteria, fungi, protozoa, and actinomycetes—regulate decomposition and nutrient fluxes. Their diversity and abundance are highly sensitive to pesticide residues. For instance, chlorpyrifos reduces nitrogen-fixing bacteria like *Rhizobium* (Jacobsen & Hjelmsø, 2014) [7]. Similarly, glyphosate has been shown to decrease beneficial fungi including arbuscular mycorrhizal fungi (AMF) (Zaller *et al.*, 2014) [16].

3. Pesticide Persistence and Soil Health Implications
Pesticides used in farming often stay in the soil for a long time, and this long-term presence is called *pesticide persistence*. When these chemicals do not break down quickly, they start creating changes in the physical, chemical, and biological properties of soil. One of the major effects is the change in soil pH, which can become either

too acidic or too alkaline depending on the type of pesticide. Such changes disturb the natural balance of soil and create an unhealthy environment for soil organisms.

Pesticide persistence also affects soil organic carbon, which is very important for soil fertility. Organic carbon helps in holding soil particles together, improving structure, water-holding capacity, and nutrient availability. But when pesticides stay in soil for too long, they slowly reduce organic carbon content and disturb microbial activity. Many soil microbes such as bacteria and fungi are responsible for decomposition and nutrient cycling. When these microbes get exposed to pesticides for a long time, their population and activity decrease, which ultimately reduces soil productivity.

Soil enzymatic activity is another major aspect of soil health. Enzymes like dehydrogenase, urease, and phosphatase help in nutrient breakdown and make nutrients available for plants. Persistent pesticides interfere with these enzymes and reduce their functioning. This leads to slower nutrient cycling and poor soil health.

Neonicotinoid group pesticides, especially imidacloprid, are known for their long persistence. Research shows that imidacloprid can remain active in soil for more than 100 days, creating long-term stress on non-target organisms (Bonmatin *et al*., 2015) [2]. Because of this long activity, even low concentrations can cause chronic toxicity to soil insects, earthworms, ants, and microorganisms. These organisms are essential for maintaining soil structure and fertility, so their decline affects the entire soil ecosystem.

Vegetation plays a central role in shaping ant nest architecture and in regulating the nest microclimate. Arboreal ant species rely heavily on tree canopies, where branches, leaves, and plant fibres serve as both the structural foundation and raw materials for nest construction. These ants frequently construct carton nests by chewing plant matter or weave leaves together using larval silk, resulting in suspended colonies that benefit from canopy shade, humidity regulation, and protection from ground-dwelling predators (Sahu & Agarwal, 2025) [13, 14].

Continuous use of highly persistent pesticides results in bioaccumulation, meaning that chemical residues keep building up in the soil year after year. This makes soil less capable of supporting healthy plant growth and reduces the natural ability of soil to recover from disturbance. Over time, this can lead to soil degradation, reduced crop productivity, and imbalance in soil biodiversity.

Methodology

In this study, I followed a simple and clear methodology so that data collection and analysis could be done properly. The research work was carried out in Janjgir–Champa district, where I selected different villages for collecting soil samples, ant samples, and other ecological data. The villages were chosen based on two conditions:

1. Areas where pesticides are used in high amounts, and
2. Areas where pesticide use is very low or almost absent (control sites).

This comparison helped me understand the real impact of pesticides on ants and soil microorganisms.

a. Sampling Site Selection

First, I visited the selected villages and identified agricultural fields where farmers regularly use chemical pesticides. Along with this, I also chose nearby fields or open areas where farming disturbance is minimum. These control sites helped in comparing natural soil conditions with pesticide-affected soil.

b. Soil Sample Collection

From each site, soil samples were collected using a clean soil auger. I collected samples from the upper 0–15 cm depth because most soil organisms, organic matter, and pesticide residues stay in this layer. Each sample was stored in labeled plastic bags and brought to the laboratory for further analysis.

c. Ant Sampling

For ant collection, I used simple methods like:

- **Hand picking**,
- **Pitfall traps**, and
- **Leaf-litter examination**.

Pitfall traps were small plastic cups placed in the soil with soapy water inside. These traps were left for 24 hours to catch ground-dwelling ants. All collected ants were preserved in 70% alcohol and later identified with the help of identification keys.

d. Microbial Analysis (CFU Count)

To study soil microorganisms, soil samples were taken to the lab where serial dilution and plating methods were used. The microbial colonies that appeared on nutrient agar plates were counted as CFUs (colony-forming units). This helped in understanding how pesticide use affects soil bacteria and fungi.

e. Soil Enzyme Tests

Two important enzymes—dehydrogenase and urease—were tested in the laboratory. These enzymes show how active soil microbes are. Lower enzyme activity means soil health is affected by pesticides.

f. Soil Physicochemical Tests

I also measured soil pH and soil organic carbon because these two factors are basic indicators of soil quality. Changes in pH or organic carbon show disturbance in soil conditions.

g. Data Analysis

After collecting all data, I compared pesticide-intensive fields with control sites. Ant diversity, microbial counts, enzyme activity, and soil parameters were analyzed to understand how pesticides are influencing soil ecosystems in Janjgir–Champa district.

This simple and systematic methodology helped me get clear and reliable results for the research.

Effect of Pesticides on Ant Community Structure

1. Decline in Ant Abundance

Pesticides reduce ant abundance by affecting their nervous system function and foraging behaviour. Neonicotinoids bind to nicotinic acetylcholine receptors, leading to paralysis and death (Tomizawa & Casida, 2005) [15]. The reduction in worker ants limits colony growth and reproduction.

2. Species Composition Shifts

Frequent pesticide exposure eliminates sensitive species and favours only pesticide-tolerant ants such as *Tapinoma* *melanocephalum*. Studies confirm that ant species richness decreases significantly in intensively managed farmlands (Lopes & Vasconcelos, 2011) [9].

3. Disturbance in Nesting and Relocation Dynamics

Soil contamination reduces nest-building capacity because pesticides destroy microbial communities responsible for organic matter decomposition. Ants frequently relocate nests in pesticide-exposed soils due to poor soil quality (Philpott & Armbrecht, 2006) [11].

4. Impacts on Ant Behaviour and Foraging

Pesticides impair ant communication by disrupting pheromone trails. Laboratory experiments show that imidacloprid reduces trail-following efficiency in *Solenopsis invicta* (Chen, 2012) [3].

Effect of Pesticides on Soil Microbial Diversity

1. Decline in Bacterial Diversity

Chlorpyrifos and malathion reduce beneficial bacteria like *Azotobacter* and *Rhizobium* (Ahemad & Khan, 2010) [1]. A reduction in nitrogen-fixing bacteria decreases soil fertility and plant productivity.

2. Suppression of Fungal Communities

Fungicides and herbicides disrupt fungal mycelial growth, especially AMF colonization of plant roots. AMF plays an essential role in phosphorus uptake; however, glyphosate-treated soil shows 40–60% reduction in AMF spores (Zaller *et al*., 2014) [16].

3. Reduction in Soil Enzymatic Activity

Soil enzymes such as dehydrogenase, phosphatase, and urease decline significantly in pesticide-contaminated soil (Cycoń *et al*., 2010) [4]. These enzymes are crucial for nitrogen and phosphorus cycling.

4. Shift in Microbial Functional Groups

Pesticides favour opportunistic species while suppressing slow-growing, functionally important microbes such as actinomycetes (Paul, 2014) [10]. This imbalance weakens soil resilience.

Ant–Microbe Interactions under Pesticide Stress

Ants depend on microbes for:

- decomposition of organic material
- nutrient availability
- maintenance of soil structure

Microbial decline disrupts ant diet, increases nest relocation frequency, and reduces colony success. According to ecological models, loss of microbial diversity indirectly destabilizes ant population dynamics (Philpott & Armbrecht, 2006) [11].

Ecological Implications

Agricultural pesticides do not only affect soil organisms directly, but they also create long-term ecological changes in the entire environment. When ants, microbes, and other small organisms start declining, it affects the complete functioning of the ecosystem. This section explains how pesticide use leads to soil degradation, disturbs food-web interactions, and reduces natural ecological services like pollination and pest control.

1. Soil Degradation

Soil degradation is one of the most important impacts of pesticide use. Soil health depends largely on microorganisms such as bacteria and fungi, because they help in decomposition, nutrient recycling, organic matter formation, and maintaining soil structure. When pesticides kill or reduce these microbes, the essential soil processes become weak. Microbe-mediated processes like nitrogen fixation, organic matter breakdown, and enzyme activity slow down. As a result, soil fertility decreases, and the soil loses its natural ability to support healthy plant growth. Over time, continuous use of pesticides can make the soil hard, compact, and poor in nutrients, which increases the dependency on chemical fertilizers. Thus, soil degradation caused by microbe decline creates a cycle of poor soil health and reduced productivity.

2. Break-down of Food Web Interactions

Ants play a very important role in maintaining terrestrial food webs. They act as predators, controlling small insect pests; as seed dispersers, helping plants to spread; and as scavengers, cleaning the environment by removing dead insects and organic matter. When pesticides reduce ant populations, these ecological roles are disturbed. The decline of ants also affects the animals that depend on ants as a food source. This creates an imbalance in the food web where some pests may increase due to the absence of natural predators. The loss of seed-dispersing ants can also slow down plant regeneration, affecting vegetation patterns. Therefore, even a small reduction in ant diversity can create a chain reaction throughout the ecosystem.

3. Loss of Pollination and Pest Regulation Services

Some ant species indirectly contribute to pollination by visiting flowers, while others protect plants from herbivores like caterpillars and aphids. These ants act as natural bodyguards for plants. But when pesticides kill these beneficial ants, plants lose a natural protection system. As a result, pest populations may increase, causing more crop damage. This forces farmers to depend even more on chemical pesticides, making the problem worse. Additionally, the decline of ant-mediated pollination reduces plant reproduction and seed formation in some crops and wild plants.

In summary, the ecological implications of pesticide use are wide-ranging. Soil degradation, breakdown of food webs, and loss of natural ecological services show that pesticides not only harm small organisms but also weaken the stability and sustainability of the entire ecosystem.

Strategies for Mitigation

Sustainable management of agricultural ecosystems requires strategies that reduce pesticide-driven ecological damage while maintaining farm productivity. Several approaches have been developed to minimize the negative effects on ants, soil microorganisms, and overall soil health.

1. Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is considered one of the most effective and eco-friendly approaches to agricultural pest control. IPM focuses on combining biological, cultural, physical, and chemical control methods to minimize pesticide dependence. According to Kogan (1998) [8], IPM aims to maintain pest populations below economic thresholds while simultaneously reducing unnecessary pesticide applications, thereby protecting beneficial soil fauna and microbial communities.

IPM strategies include crop rotation, use of pest-resistant crop varieties, mechanical control (traps, barriers), habitat manipulation, and targeted pesticide use only when absolutely necessary. These measures collectively help reduce chemical inputs, resulting in lower contamination of soil and reduced mortality of ant species that serve as indicators of soil quality (Kogan, 1998) [8]. By conserving natural enemies and enhancing biological control, IPM ultimately supports healthier soil ecosystems.

2. Organic Amendments

Organic amendments such as compost, vermicompost, green manure, and biofertilizers are widely recognized for improving soil fertility and enhancing biological activity. These amendments increase organic matter content, promote nutrient cycling, and stimulate the growth and diversity of beneficial soil microbes. Research has shown that organic inputs significantly restore microbial communities that are often disrupted by continuous pesticide exposure (Pérez-Piqueres *et al*., 2006).

Compost introduces diverse microbial populations that help re-establish ecological balance in the soil, while biofertilizers (e.g., nitrogen-fixing bacteria, phosphate-solubilizing bacteria) promote plant growth without chemical inputs. Improved microbial activity also supports ant nesting and foraging behavior, as ants prefer soils with greater organic matter and microhabitat stability. Thus, organic amendments not only revive soil microbial health but also promote the recovery of ant community structure.

3. Biopesticides

Biopesticides represent an environmentally safer alternative to synthetic chemical pesticides. These include microbial pesticides, botanical extracts, and bio-derived compounds that target specific pests while causing minimal harm to non-target organisms. Among microbial biopesticides, *Bacillus thuringiensis (Bt)* is one of the most widely used agents. Bt produces toxins that affect specific insect groups but do not significantly harm soil microbes or beneficial insects including most ant species (Lacey *et al*., 2015).

Because biopesticides degrade faster and exhibit narrow host specificity, they contribute less to soil pollution and help maintain soil ecological balance. Their selective action preserves natural predators, parasitoids, decomposers, and soil engineers—functions performed by ants and microorganisms. Therefore, integrating biopesticides into pest management programs can play a key role in reducing pesticide-related disruptions to soil biodiversity.

Conclusion

Pesticides exert profound negative impacts on both ant community structure and soil microbial diversity. They reduce ant abundance, disrupt nesting behaviour, shift species composition, and impair ecological functions. Similarly, pesticide residues suppress microbial biomass, enzymatic activity, and nutrient cycling. Ant–microbe interactions collapse under pesticide stress, causing long-term soil degradation. Sustainable alternatives, including IPM and organic practices, are essential for biodiversity conservation and ecosystem health.

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