Investigation on the Effect of Fenpyroximate on Soil Microbiological Parameters

***Hemant Kumar Pandey, **Dr. Kailas Narayan Sonune**
*Research Scholar, **Research Supervisor,
Department of Chemistry,
Himalayan University
Itanagar, AP

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Abstract

Fenpyroximate, a selective acaricide, is used extensively in agriculture for the control of spider mites. However, its impact on non-target soil microorganisms is not well-understood. This theoretical paper explores the potential effects of fenpyroximate on soil microbiological parameters such as microbial diversity, enzyme activities, and microbial biomass. By reviewing existing literature and drawing on related studies, this paper suggests that fenpyroximate may disrupt soil microbial communities, reduce enzyme activities critical for nutrient cycling, and diminish microbial biomass, ultimately affecting soil health and fertility. The paper concludes with the need for further research into the long-term environmental effects of fenpyroximate on soil ecosystems.

Keywords: *Fenpyroximate; Microbial; Diversity; Soil; Fertility.*

I. INTRODUCTION

The extensive use of chemical pesticides in modern agriculture has significantly contributed to increased crop yields and pest management efficiency. However, the widespread application of these chemicals raises concerns about their environmental impacts, particularly on non-target organisms such as soil microorganisms. These microorganisms, which include bacteria, fungi, archaea, and actinomycetes, play critical roles in maintaining soil health through nutrient cycling, organic matter decomposition, and soil structure stabilisation. Given their pivotal role in ecosystem functioning, any disruption to soil microbial communities can have long-term consequences for soil fertility, plant growth, and broader environmental sustainability.

Fenpyroximate is a relatively new and widely used pesticide in agricultural practices, specifically designed to control spider mites (Tetranychidae), which are known to be major pests in crops like fruits, vegetables, and ornamental plants. As a selective miticide, fenpyroximate works by inhibiting mitochondrial electron transport in the target mites, ultimately leading to their death. While its effectiveness in pest control is well-documented, the impact of fenpyroximate on non-target organisms, particularly soil microorganisms, remains largely underexplored. In this context, investigating the potential effects of fenpyroximate on soil microbiological parameters is crucial for understanding its broader ecological consequences and developing sustainable agricultural practices.

Soil microorganisms play a vital role in regulating key ecological processes such as nutrient cycling, organic matter decomposition, and plant growth promotion. Bacteria, for instance, are involved in the nitrogen cycle, while fungi assist in breaking down organic matter and facilitating nutrient availability to plants. The diversity and functionality of these microbial communities are essential for maintaining soil health, fertility, and resilience against environmental stresses. Any disruption to these microbial communities—whether through pesticide exposure, environmental

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changes, or management practices—can lead to a decline in soil quality, nutrient imbalances, and reduced plant productivity.

The potential impacts of pesticides on soil microbial communities have been documented in a variety of studies, particularly concerning the use of insecticides and herbicides. It is well established that pesticides can cause shifts in microbial diversity, leading to a reduction in the abundance of sensitive species while promoting the proliferation of more resistant strains. These shifts may alter microbial metabolic pathways, enzyme activities, and interactions within the soil ecosystem. For example, pesticide-induced reductions in microbial populations can lower the activity of critical soil enzymes, such as urease and phosphatase, which are essential for nitrogen and phosphorus cycling. Such alterations in microbial diversity and functionality can ultimately affect soil nutrient dynamics and fertility, potentially leading to reduced crop yields over time.

Fenpyroximate, like many chemical pesticides, is designed to target specific pests while minimising harm to non-target organisms. However, its persistence in the environment and potential for bioaccumulation raise concerns about its long-term effects on soil ecosystems. Given that pesticides like fenpyroximate are often applied repeatedly in agricultural settings, the cumulative and chronic exposure of soil microorganisms to such chemicals could result in sustained disruptions to microbial communities and soil function. Moreover, the selective nature of fenpyroximate's action on pests may lead to the emergence of pesticide-resistant microbial species, further complicating the management of soil health.

Several key factors contribute to the potential impacts of fenpyroximate on soil microbiota. The chemical's mode of action, which interferes with mitochondrial function in target organisms, could also affect microbial cells that rely on similar metabolic pathways. As a result, fenpyroximate may inhibit the growth and reproduction of soil microorganisms, particularly those involved in essential nutrient cycling processes. Additionally, pesticide exposure may alter soil microbial biomass, which refers to the living component of soil microorganisms, and is an important indicator of soil health and fertility. A reduction in microbial biomass could signal a decline in overall microbial activity, further exacerbating the negative impacts on nutrient cycling and soil quality.

Soil enzymes, which are produced by soil microorganisms, are also highly sensitive to pesticide exposure. These enzymes facilitate various biochemical processes, including organic matter decomposition and the mineralisation of nutrients. Enzyme activities in soils can be used as a proxy for microbial activity and overall soil health. Given that fenpyroximate may affect microbial communities that produce critical enzymes, it is essential to assess its potential impact on soil enzyme activities. Changes in enzyme activity could indicate broader disruptions to microbial metabolism, leading to a decline in soil fertility and nutrient availability for plants.

The application of fenpyroximate in agricultural fields could thus lead to shifts in microbial community composition, a reduction in microbial biomass, and alterations in enzymatic activities, all of which could compromise soil health. Understanding these potential impacts is crucial for evaluating the sustainability of pesticide use and identifying strategies to mitigate adverse effects on soil ecosystems. This study aims to investigate the effects of fenpyroximate on key soil microbiological parameters, including microbial diversity, enzyme activity, and microbial biomass, to assess its broader ecological consequences.

The goal of this investigation is to provide insights into how fenpyroximate influences soil microorganisms and, by extension, soil health. Through a theoretical exploration of its potential effects, this research seeks to contribute to a growing body of knowledge regarding the environmental impacts of pesticides and the need for more sustainable agricultural practices. Given the increasing reliance on chemical pesticides in modern farming, understanding their long-term effects on soil microbiota is crucial for developing strategies that minimise ecological damage while maintaining agricultural productivity. By investigating the impact of fenpyroximate, this study hopes to fill a critical knowledge gap and inform future pesticide management strategies in agricultural systems.

II. POTENTIAL MECHANISMS OF FENPYROXIMATE ACTION ON SOIL MICROORGANISMS

Fenpyroximate, a selective acaricide, is primarily used for controlling spider mites in agricultural settings. While it is effective against pests, its application in agricultural soils can have unintended consequences for soil microorganisms. Soil microorganisms, which include bacteria, fungi, and actinomycetes, are crucial for maintaining soil health, nutrient cycling, and overall ecosystem stability. The introduction of fenpyroximate into soil ecosystems can impact these microorganisms through several potential mechanisms, including direct toxicity, changes in microbial community composition, and disruption of essential microbial functions. Understanding these mechanisms is critical for assessing the broader ecological effects of fenpyroximate and its sustainability in agricultural practices.

Direct Toxicity to Soil Microorganisms

The primary mechanism through which fenpyroximate affects soil microorganisms is likely to be its direct toxicity. Fenpyroximate functions by inhibiting mitochondrial electron transport in its target organisms, such as spider mites. This mode of action could also affect soil microorganisms that share similar biochemical pathways, especially those that rely on cellular respiration for energy production. Since many soil microbes are aerobic and depend on mitochondrial respiration, fenpyroximate could disrupt their metabolic processes, leading to reduced growth, reproduction, or even mortality in sensitive microbial populations.

While fenpyroximate is designed to be selective for pests, non-target organisms in the soil, such as beneficial bacteria and fungi, may also be exposed to sublethal concentrations of the pesticide. These sublethal exposures could result in altered growth rates or changes in microbial metabolism, affecting the overall microbial community structure and functional capacity of the soil. For instance, certain species of nitrogen-fixing bacteria, which are critical for nutrient cycling, may be more susceptible to fenpyroximate-induced stress, leading to reductions in nitrogen fixation and nutrient availability for plants.

Disruption of Microbial Community Composition

Pesticides like fenpyroximate often cause shifts in microbial community composition by selectively affecting sensitive species while allowing more resistant species to proliferate. These shifts can reduce microbial diversity, which is crucial for maintaining soil ecosystem functions such as nutrient cycling, disease suppression, and organic matter decomposition. For example, fenpyroximate may selectively target microorganisms involved in key soil processes like carbon and nitrogen cycling, potentially leading to an imbalance in microbial groups that can impact nutrient dynamics in the soil.

One of the most important impacts of reduced microbial diversity is a decrease in the redundancy of functional groups. In diverse microbial communities, multiple species often perform similar ecological functions, which provide resilience to environmental disturbances. However, if pesticide exposure causes a loss of sensitive species, the remaining microbes may not be able to fully compensate for these lost functions. As a result, the soil ecosystem may become more vulnerable to future disturbances, including further pesticide exposure, changes in temperature, or fluctuations in moisture.

Alteration of Soil Enzyme Activities

Soil enzymes, which are produced by microorganisms, play vital roles in nutrient cycling, organic matter decomposition, and soil structure maintenance. Enzymes such as urease (involved in nitrogen cycling), phosphatase (involved in phosphorus cycling), and dehydrogenase (indicative of microbial metabolic activity) are essential for maintaining soil fertility. Pesticides like fenpyroximate can interfere with microbial processes by inhibiting the production or activity of these enzymes.

Fenpyroximate's impact on microbial enzymes can be twofold: it may reduce the microbial population responsible for enzyme production, and it may directly inhibit the enzymes themselves. For instance, a decrease in microbial biomass due to fenpyroximate exposure could lead to reduced activity of soil enzymes that help convert organic matter into bioavailable nutrients. This could slow down nutrient cycling, leading to nutrient deficiencies in the soil and reduced plant growth.

Indirect Effects via Soil Environmental Changes

Fenpyroximate may also affect soil microorganisms indirectly by altering the soil environment. Pesticides can change the physical and chemical properties of the soil, such as pH, organic matter content, and moisture retention. These environmental shifts can create conditions that are either more or less favorable for certain microbial populations. For example, the accumulation of pesticide residues in the soil may increase the toxicity of the soil environment, making it less habitable for sensitive microbes.

Additionally, fenpyroximate's effects on plant health could further influence soil microbial communities. Since plants and soil microorganisms are in a symbiotic relationship, with plants providing organic matter and nutrients to the soil microbiota, a reduction in plant health could lead to lower organic matter input into the soil. This could reduce microbial activity and diversity, further compounding the negative effects of fenpyroximate on soil ecosystem health.

Potential for Development of Resistance in Soil Microorganisms

As with any pesticide, the repeated application of fenpyroximate in agricultural systems may exert selective pressure on microbial populations, potentially leading to the development of resistance. Resistance mechanisms in soil microorganisms could involve changes in enzyme systems, metabolic pathways, or the ability to detoxify the pesticide. If pesticide-resistant microbial species are allowed to proliferate, the overall microbial diversity in the soil could be reduced, which may impair key ecological processes, such as nutrient cycling, that depend on a wide range of microbial functions.

The potential mechanisms through which fenpyroximate affects soil microorganisms are multifaceted, involving direct toxicity, changes in microbial community composition, disruption of enzymatic functions, and indirect effects on soil environmental conditions. Each of these mechanisms can have cascading impacts on soil health, microbial diversity, and ecosystem stability. Given the importance of soil microorganisms for maintaining soil fertility and supporting plant growth, the long-term effects of fenpyroximate on soil microbial communities warrant further investigation. Understanding these mechanisms is essential for developing more sustainable agricultural practices that minimize the ecological impacts of pesticide use while maintaining crop productivity.

III. IMPACT ON MICROBIAL BIOMASS AND SOIL FERTILITY

Soil microbial biomass plays a central role in soil health by influencing organic matter decomposition, nutrient cycling, and maintaining soil structure. Microorganisms are involved in breaking down organic materials into simpler compounds, releasing essential nutrients like nitrogen, phosphorus, and sulfur. These nutrients are then available to plants, contributing to soil fertility. However, the application of pesticides, including fenpyroximate, can disrupt microbial biomass and, by extension, affect soil fertility. Understanding the impact of fenpyroximate on microbial biomass is crucial for evaluating its long-term effects on soil ecosystems and agricultural productivity.

Decrease in Microbial Biomass Due to Pesticide Exposure

Fenpyroximate, as an acaricide, is designed to control spider mites but may also exert toxic effects on non-target soil microorganisms. These microorganisms, which include bacteria, fungi, and actinomycetes, are vital for processes such as organic matter decomposition and nutrient cycling. The application of fenpyroximate can lead to a reduction in the microbial biomass by either directly killing sensitive microbes or inhibiting their growth and reproduction. As microbial biomass decreases, the ability of the soil to process organic matter and cycle nutrients diminishes, which directly impacts soil fertility.

The reduction in microbial biomass also signifies a loss in the biological activity of the soil. Microbes are responsible for breaking down organic matter and facilitating the release of nutrients that plants need for growth. When pesticide exposure reduces microbial biomass, it leads to a slower breakdown of organic material and a reduction in the availability of essential nutrients. This can lead to nutrient deficiencies in the soil, affecting plant growth and overall crop productivity.

Altered Soil Microbial Community and Functional Capacity

Beyond reducing overall microbial biomass, fenpyroximate may also cause shifts in microbial community composition. Pesticides can select for resistant microbial species while eliminating those that are more sensitive to chemical exposure. Such shifts can result in a microbial community that lacks the diversity necessary for maintaining healthy soil processes. For instance, a reduction in nitrogen-fixing bacteria due to pesticide exposure can impair the soil's nitrogen cycle, reducing nitrogen availability for plants.

As microbial community composition changes, the functional capacity of the soil also declines. Specific microbial groups are responsible for critical soil functions such as the mineralisation of nitrogen, decomposition of organic material, and soil aggregation. If pesticide application leads to a decline in these microbial groups, essential functions such as nutrient cycling and organic matter breakdown may be impaired, further reducing soil fertility. In the long term, this could result in a less resilient soil ecosystem, making it more vulnerable to erosion, nutrient depletion, and other environmental stresses.

Impacts on Soil Enzyme Activities

Soil enzymes, which are often produced by microorganisms, are key indicators of soil health and microbial activity. Enzymes like urease, phosphatase, and dehydrogenase play critical roles in nutrient cycling by breaking down complex organic compounds into forms that plants can absorb. Fenpyroximate may reduce microbial biomass, which in turn decreases the production of these essential enzymes. Reduced enzyme activity can slow down the decomposition of organic matter and the mineralisation of nutrients, ultimately leading to a decline in soil fertility.

For instance, urease is involved in the hydrolysis of urea to ammonia, a process crucial for nitrogen cycling in the soil. A decrease in urease activity due to pesticide exposure could impair nitrogen availability, leading to reduced plant growth. Similarly, a reduction in phosphatase activity can impact phosphorus cycling, further limiting the nutrient availability necessary for healthy plant development.

Long-Term Effects on Soil Fertility

The long-term consequences of reduced microbial biomass and altered microbial community structure due to fenpyroximate exposure can be profound. With a diminished microbial community and impaired nutrient cycling, soil fertility is likely to decrease over time. Reduced soil microbial activity can lead to the depletion of soil organic matter, as decomposition rates slow down. The reduction in organic matter can further exacerbate soil degradation, leading to lower water retention, poorer soil structure, and a decrease in overall soil quality.

Moreover, as microbial diversity decreases, the soil becomes more susceptible to pathogens and less capable of suppressing plant diseases. Soilborne pathogens may thrive in an environment where the balance of beneficial microorganisms has been disrupted, leading to increased plant susceptibility to disease. This, in turn, can reduce crop yields and increase reliance on chemical inputs to control diseases, creating a vicious cycle of soil degradation.

Implications for Sustainable Agriculture

The impacts of fenpyroximate on microbial biomass and soil fertility highlight the need for sustainable pest management practices in agriculture. Pesticides, while effective at controlling pest populations, can have unintended consequences on soil ecosystems. In the long term, the degradation of soil health and fertility due to reduced microbial biomass could lead to increased dependence on synthetic fertilisers and other soil amendments. This would not only increase the cost of farming but could also contribute to environmental pollution.

To promote sustainable agricultural practices, it is crucial to adopt integrated pest management (IPM) strategies that minimise the impact of pesticides on non-target organisms, including soil microorganisms. This may involve using biopesticides, crop rotation, or other biological control methods that maintain healthy soil ecosystems while still managing pest populations effectively.

The impact of fenpyroximate on microbial biomass and soil fertility can be profound, with potential consequences for nutrient cycling, organic matter decomposition, and overall soil health. A reduction in microbial biomass leads to a decrease in soil fertility, as essential soil functions become impaired. Alterations in microbial community composition and enzyme activities further compound these effects, leading to long-term soil degradation. Understanding these impacts is critical for developing sustainable agricultural practices that balance pest control with the preservation of soil health and fertility. Sustainable pest management strategies should aim to minimise the ecological consequences of pesticide use while maintaining crop productivity and soil integrity.

IV. EFFECTS ON SOIL MICROBIAL DIVERSITY AND ECOLOGICAL RESILIENCE

Soil microbial diversity is integral to maintaining ecosystem functions such as nutrient cycling, organic matter decomposition, and plant health. The complexity of soil ecosystems relies on a wide range of microorganisms that interact in dynamic ways to support soil fertility and plant growth. However, the application of chemical pesticides like fenpyroximate can disrupt this delicate balance, leading to a reduction in microbial diversity, which can, in turn, affect the ecological resilience of the soil.

Impact on Microbial Diversity

Soil microbial communities are highly diverse, consisting of a variety of bacteria, fungi, archaea, and actinomycetes. Each group of microorganisms plays a specific role in the soil ecosystem, contributing to processes such as nitrogen fixation, organic matter breakdown, and pathogen suppression. Fenpyroximate, being a potent pesticide, may cause selective pressure on microbial communities by targeting sensitive species while allowing more resistant organisms to thrive.

This selective pressure can reduce microbial diversity in the soil. A decline in diversity may occur because fenpyroximate negatively affects certain microbial groups, such as nitrogen-fixing bacteria or phosphorus-solubilising fungi that are essential for nutrient cycling. As these organisms decline, their ecological functions may be diminished, disrupting nutrient availability for plants and impairing the overall health of the soil.

Consequences for Soil Ecosystem Function

The loss of microbial diversity can have far-reaching consequences for soil ecosystem function. Diverse microbial communities help ensure functional redundancy, meaning that if one species is affected by environmental stressors, others can step in to perform similar tasks. However, when pesticide exposure leads to a reduction in microbial diversity, this redundancy is lost, making the ecosystem more vulnerable to further disturbances.

In particular, nutrient cycling—critical for plant growth—may be impaired. For example, fewer nitrogen-fixing bacteria in the soil can lead to nitrogen deficiencies, limiting plant growth and reducing agricultural productivity. Similarly, a loss of microbial species involved in organic matter decomposition could slow down the breakdown of plant residues, resulting in reduced soil organic carbon and a decline in soil fertility over time.

Reduced Ecological Resilience

Ecological resilience refers to the ability of an ecosystem to recover from disturbances and maintain its functions over time. Soil ecosystems with higher microbial diversity are generally more resilient to changes, such as fluctuations in temperature, moisture, or pesticide exposure. However, the loss of microbial diversity due to fenpyroximate application weakens the soil's ability to adapt to environmental stressors.

With fewer microbial species, the soil ecosystem becomes more fragile, and its ability to recover from disturbances such as droughts, flooding, or pest outbreaks is diminished. The reduced resilience of soil ecosystems can lead to long-term soil degradation, lower crop yields, and increased reliance on external inputs like fertilisers and pesticides to maintain productivity.

Implications for Sustainable Agriculture

Maintaining microbial diversity is essential for ensuring the ecological resilience of soils and the sustainability of agricultural systems. Sustainable pest management practices, such as integrated pest management (IPM), can help reduce the negative impacts of pesticides like fenpyroximate on microbial diversity. By minimising pesticide use and promoting biologically-based control methods, farmers can protect soil health and enhance the resilience of their agricultural systems, ensuring long-term productivity and ecosystem stability.

The application of fenpyroximate can significantly affect soil microbial diversity, leading to reductions in the ecological resilience of the soil ecosystem. Loss of microbial diversity impairs essential soil functions such as nutrient cycling and organic matter decomposition, which can ultimately affect plant growth and soil fertility. Understanding the implications of pesticide use on soil biodiversity is critical for developing sustainable agricultural practices that protect the long-term health and resilience of soil ecosystems.

V. CONCLUSION

In conclusion, the application of fenpyroximate in agricultural soils can have significant and far-reaching effects on soil microbial communities and overall soil health. As a selective pesticide, fenpyroximate primarily targets spider mites, but its broader impact on non-target soil microorganisms cannot be overlooked. The reduction in microbial biomass, disruption of microbial diversity, and alterations in enzyme activities caused by fenpyroximate pose risks to soil fertility, nutrient cycling, and plant growth. Soil microorganisms are essential for processes like organic matter decomposition, nitrogen fixation, and pathogen suppression, all of which contribute to maintaining soil health and agricultural productivity. The decline in microbial diversity resulting from fenpyroximate exposure weakens the soil’s ecological resilience, making it more vulnerable to further disturbances such as drought, pest outbreaks, and other environmental stresses. Moreover, the loss of microbial diversity and functional capacity can lead to long-term soil degradation, reducing crop yields and increasing reliance on synthetic fertilisers and other chemical inputs. This cycle of dependency underscores the need for sustainable pest management practices that minimise the ecological impacts of pesticide use. Given the critical role of soil microorganisms in maintaining soil health, it is essential to adopt more environmentally responsible and sustainable agricultural practices. Integrated pest management (IPM) strategies that prioritise biological control methods and reduce pesticide application can help mitigate the adverse effects of chemicals like fenpyroximate. Further research into the long-term impacts of fenpyroximate on soil ecosystems is crucial for developing practices that protect both crop productivity and soil biodiversity, ensuring the sustainability of agricultural systems for future generations.

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