Review Article

Impact of plant allelochemicals on soil properties: A review

ABSTRACT

Allelochemicals are natural compounds produced by plants that can affect the growth and development of other plants and microorganisms in their surrounding environment. In recent years, there has been growing interest in understanding the impact of allelochemicals on soil properties. This review aims to provide a comprehensive overview of the current understanding of the effects of allelochemicals on soil properties, including soil organic matter, nutrient cycling, microbial diversity, and soil physical properties. Several studies have shown that allelochemicals can have both positive and negative effects on soil properties depending on the concentration and duration of exposure. For instance, low concentrations of allelochemicals can stimulate microbial activity and improve soil fertility by increasing nutrient availability, while high concentrations can have toxic effects and reduce microbial diversity. Additionally, allelochemicals can also influence soil physical properties such as soil structure, porosity, and water-holding capacity. For example, some allelochemicals can cause soil compaction and reduce water infiltration, while others can improve soil aggregation and enhance water-holding capacity. Overall, the impact of allelochemicals on soil properties is complex and context-dependent, and further research is needed to fully understand the mechanisms underlying these effects. Nonetheless, understanding the role of allelochemicals in soil ecosystems has important implications for agriculture and ecosystem management, and can help us develop more sustainable and efficient soil management practices.

Keywords: Allelochemicals, Soil properties, soil fungi, Microbial diversity

1. INTRODUCTION

Allelochemicals are natural compounds produced by plants that can affect the growth and development of other plants and microorganisms in their surrounding environment. These compounds are released into the soil through various mechanisms, such as leaching, volatilization, or decomposition of plant residues. The impact of allelochemicals on soil properties has been a topic of increasing interest in recent years. Several studies reveal the potential of these compounds to influence soil fertility, nutrient cycling, microbial diversity, and soil physical properties. Studies have shown that allelochemicals can have both positive and negative effects on soil properties depending on the concentration and duration of exposure. Allelochemicals can also influence soil physical properties such as soil structure, porosity, and water-holding capacity. Understanding the role of allelochemicals in soil ecosystems has important implications for agriculture and ecosystem management, and can help us develop more sustainable and efficient soil management practices. Wu et al. (2001) investigated the variation of phenolic acids in wheat shoot tissues and their potential allelopathic effects on other plants. They found that wheat tissues contained high levels of phenolic acids, which could inhibit the growth of other plants by reducing their nutrient uptake and photosynthetic efficiency [1]. Zhang et al. (2021) explored the allelopathic potential of microorganisms associated with seaweeds and marine animals. They found that these microorganisms produce a range of allelochemicals that can inhibit the growth of other microorganisms and plants, suggesting that they play an important role in influential marine ecosystems [2]. Khanh et al. (2005) examined the effects of allelochemicals from barnyard grass on rice growth. They found that barnyard grass allelochemicals had both positive and negative effects on rice growth, depending on the concentration and duration of exposure. At low concentrations, the allelochemicals stimulated rice growth, while at high concentrations they inhibited growth [3]. Kato-Noguchi and Ino (2008) investigated the allelopathic potential of several weed species on the germination and growth of barnyard grass. They found that some weed species, such as chickweed and shepherd's purse, had strong allelopathic effects on barnyard grass, while others had little or no effect [4]. Khanh et al. (2007) reviewed the allelopathic potential of rice and its potential for weed management. They found that rice produces a range of allelochemicals that can inhibit the growth of many weed species, suggesting that intercropping rice with other crops or planting rice as a cover crop could be an effective weed management strategy [5]. These studies provide insights into the complex interactions between allelochemicals and soil properties, and highlight the potential for these compounds to influence ecosystem dynamics and agricultural practices. These studies explore various aspects of allelochemicals and their impact on soil properties, including their effects on nutrient availability, soil microbial communities, and plant growth. Some studies focus on specific allelochemicals or plant species, while others take a broader approach to understanding the ecological roles of allelochemicals in soil ecosystems. Overall, these studies demonstrate the complex and multifaceted relationships between allelochemicals and soil properties, and highlight the need for further research to fully understand these interactions. These studies explore various aspects of allelochemicals and their impact on soil properties, including their effects on nutrient availability, soil microbial communities, and plant growth. Some studies focus on specific allelochemicals or plant species, while others take a broader approach to understanding the ecological roles of allelochemicals in soil ecosystems. Liang et al. (2015) investigated the allelopathic effects of rice residues on the seed germination and seedling growth of Chinese milk vetch. They found that rice residues inhibited the growth of Chinese milk vetch, suggesting that rice residues may have a negative impact on the growth of crops that are commonly grown in rotation with rice [6]. Yu et al. (2019) explored the allelopathic effects of volatile organic compounds (VOCs) emitted from grapevine on soil microorganisms. They found that grapevine VOCs had both positive and negative effects on soil microorganisms, depending on the type and concentration of VOCs, suggesting that allelopathy may play a complex role in regulating soil microbial communities [7]. Li et al. (2015) examined the allelopathic effects of alfalfa on soil microbial community and diversity. They found that allelopathic compounds produced by alfalfa had a negative impact on soil microbial diversity and community structure, suggesting that allelopathy may have a significant impact on soil ecosystem function [8]. Zhao et al. (2018) investigated the allelopathic effects of VOCs from wheat on the seed germination of Chinese cabbage. They found that VOCs from wheat had a negative impact on Chinese cabbage seed germination, suggesting that allelopathy may play a role in regulating plant community dynamics in agricultural systems [9]. Xiao et al. (2018) explored the allelopathic effects of VOCs from cucumber on soil microbial community structure and nitrogen cycling. They found that VOCs from cucumber had both positive and negative effects on soil microbial community structure and nitrogen cycling, suggesting that allelopathy may play a complex role in regulating soil ecosystem processes [10]. These studies explore the allelopathic effects of various plant species on soil properties, including soil microorganisms, nutrient availability, and plant growth. Some studies focus on specific plant species, while others take a broader approach to understanding the ecological roles of allelopathy in soil ecosystems. These studies provide further insights into the diverse and complex interactions between allelochemicals and soil properties, and highlight the potential for these compounds to influence agricultural practices and ecosystem dynamics.

Overall, these studies highlight the diverse and complex interactions between allelochemicals and soil properties, and suggest that allelopathy may play an important role in regulating soil ecosystem dynamics. Overall, these studies demonstrate the complex and multifaceted relationships between allelochemicals and soil properties, and highlight the need for further research to fully understand these interactions.

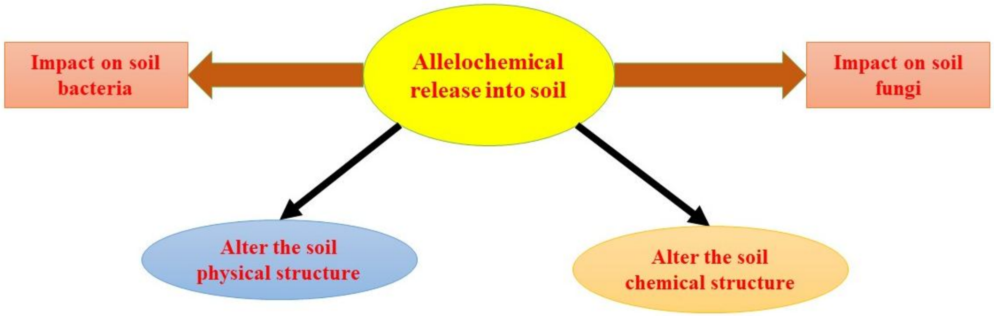

Fig 1: Probable ways of impact of allelochemical on soil

2.1 Physical characteristics of soil:

The physical characteristics of soil refer to its physical properties, such as texture, structure, porosity, and water-holding capacity. These properties are influenced by factors such as parent material, climate, topography, and biotic factors including allelopathic interactions between plants and soil microorganisms.

Allelopathy, the ability of plants to release allelochemicals that affect the growth and development of other plants and soil organisms, can influence the physical characteristics of soil. For example, some allelochemicals released by plants can affect soil structure by promoting the formation of stable aggregates or by reducing soil compaction. They can also enhance water-holding capacity and improve soil porosity by increasing soil organic matter content and promoting the growth of soil microorganisms.

However, the effect of allelochemicals on soil physical properties can also be negative. High concentrations of allelochemicals in soil can result in toxicity to soil microorganisms, which may lead to the breakdown of soil aggregates and the loss of soil structure. Furthermore, allelopathic interactions can also lead to changes in soil temperature and moisture regimes, which can further influence soil physical characteristics.

Overall, the effects of allelochemicals on soil physical characteristics are complex and depend on the type, concentration, and persistence of the allelochemicals, as well as the interactions between plants and soil organisms. Therefore, further research is needed to fully understand the role of allelopathy in shaping soil physical properties and to develop strategies for optimizing the positive effects of allelopathy while minimizing its negative impacts.

2.2 Chemical characteristics of soil:

The chemical characteristics of soil refer to the chemical properties of soil that affect plant growth and soil fertility. Some of the important chemical characteristics of soil are:

Soil pH: Soil pH is a measure of the acidity or alkalinity of the soil. The pH of soil affects nutrient availability, microbial activity, and soil structure. Most plants prefer a slightly acidic soil with a pH between 6.0 and 7.0.

Soil organic matter: Soil organic matter is composed of decomposing plant and animal residues. It affects the soil structure, water-holding capacity, and nutrient availability. Soil organic matter also plays an important role in carbon sequestration.

Cation exchange capacity (CEC): CEC is a measure of the soil's ability to hold and exchange positively charged ions such as calcium, magnesium, and potassium. Soils with high CEC tend to be more fertile because they can hold onto nutrients that would otherwise leach away.

Nutrient availability: Nutrient availability is determined by the soil's ability to release essential nutrients such as nitrogen, phosphorus, and potassium to plants. Nutrient availability is affected by factors such as soil pH, organic matter content, and soil texture.

Soil salinity: Soil salinity refers to the amount of salt in the soil. Excessive salt can negatively impact plant growth and soil structure. Soil salinity is affected by factors such as irrigation practices, climate, and soil drainage.

Overall, the chemical characteristics of soil play a vital role in determining the productivity and health of plants grown in that soil. Farmers and gardeners often test their soil to determine its chemical characteristics and adjust their management practices accordingly.

2.3 Effect of Allelochemicals on soil fungi:

Allelochemicals can have diverse effects on soil fungi, which can be beneficial or detrimental depending on the specific plant species and the concentration of allelochemicals present. Here are some examples of studies that have investigated the allelopathic effects of plant-produced chemicals on soil fungi. Wu et al. (2001) found that benzoxazinones and related compounds produced by wheat had a negative impact on the growth and activity of soil fungi [1]. Zeng et al. (2008) reported that allelopathic chemicals produced by plants such as *Salvia miltiorrhiza* and *Eucalyptus* can inhibit the growth of certain soil fungi, while stimulating the growth of others [11]. Zhou et al. (2019) investigated the allelopathic effects of flavonoids produced by alfalfa (*Medicago sativa*) on soil fungi and found that these compounds had a significant inhibitory effect on the growth of certain fungal species [12]. Yao et al. (2016) reported that allelochemicals produced by rice plants can have a positive effect on the growth and activity of arbuscular mycorrhizal fungi (AMF) in soil, which can improve nutrient uptake by plants [13]. Zhang et al. (2021) studied the allelopathic effects of volatile organic compounds (VOCs) produced by tomato plants on soil fungi and found that some VOCs had a significant inhibitory effect on fungal growth, while others had no effect or even stimulated fungal growth [15]. Fungi, including *Fusarium*, *Trichoderma*, and mycorrhizal fungi [1,10]. Actinomycetes [14] affected by several allelochemicals

These studies demonstrate that allelochemicals can have diverse effects on soil fungi, which can range from inhibition to stimulation of growth and activity, depending on the type and concentration of allelochemicals involved, as well as the specific fungal species present in the soil. Further research is needed to better understand the ecological implications of allelopathy on soil fungi and the mechanisms involved in these interactions.

2.4 Effect of Allelochemicals on soil microbial flora:

Several studies reveal that allelochemicals can have diverse and significant effects on soil microbial flora. For example, Wu et al. found that benzoxazinones and related compounds produced by wheat had a negative impact on the growth and activity of soil microorganisms [1]. Guo et al. (2017) showed that *Artemisia scoparia* essential oil had a significant inhibitory effect on soil microbial communities [14], while Zhang et al. in 2014 found that allelochemicals from rice root exudates had both positive and negative effects on soil bacteria, depending on the type and concentration of chemicals involved [15]. Cai et al. also reported significant changes in the microbial flora of soil exposed to allelochemicals from *Eupatorium adenophorum* Spreng [16]. These studies demonstrate that allelopathy can have significant impacts on soil microbial communities and highlight the need for further research to better understand the mechanisms and ecological consequences of these interactions. While the specific microbes affected by allelochemicals can vary depending on the plant species and soil conditions involved, here are some examples of microbial groups that have been shown to be impacted by allelopathy in various studies: Bacteria, including *Bacillu*s, *Pseudomona*s, and *Rhizobium* [15,16]. It's worth observing that allelopathic effects on microbial communities are often complex and can depend on a variety of factors, including the specific allelochemicals involved, their concentrations, and the soil microbial community present. Additionally, while some allelochemicals may inhibit the growth or activity of certain microbes, they may also stimulate the growth or activity of others.

2.5 Allelochemicals alters the physical structure of soil:

Allelochemicals can also affect the physical structure of soil, which can have important implications for plant growth and soil health. Here are some examples of studies that have investigated the allelopathic effects of plant-produced chemicals on the physical structure of soil: It was reported that allelopathic chemicals produced by wheat roots can increase the soil aggregate stability, which can improve soil structure and reduce soil erosion [17]. Feng et al. (2020) found that allelopathic chemicals produced by rice plants can increase soil bulk density and decrease porosity, which can have negative effects on soil aeration and water retention [18]. It was also investigated the allelopathic effects of volatile organic compounds (VOCs) produced by tomato plants on soil structure and found that these compounds can increase soil aggregate stability and improve water infiltration [19]. Zhang et al. (2016) reported that allelopathic chemicals produced by rice straw can improve soil aggregate stability and enhance soil water retention, which can promote plant growth and reduce soil

erosion [20]. Liu et al. (2015) studied the allelopathic effects of root exudates from sunflowers on soil structure and found that these compounds can increase soil aggregate stability and reduce soil bulk density, which can improve soil fertility and promote plant growth [21].
These studies suggest that allelochemicals can have diverse effects on the physical structure of soil, which can depend on the type and concentration of allelochemicals involved, as well as the specific soil properties and plant species present. Further research is needed to better understand the mechanisms involved in these interactions and to develop strategies for harnessing the positive effects of allelopathy on soil structure and plant growth.

2.6 Allelochemicals alters the chemical structure of soil:

Allelochemicals can also affect the chemical structure of soil, including the availability of nutrients and the pH level. Here are some examples of studies that have investigated the allelopathic effects of plant-produced chemicals on the chemical structure of soil: It was found that the allelochemicals produced by garlic plants can reduce soil pH and increase the levels of available phosphorus, potassium, and organic matter [7]. Jin et al. (2015) reported that allelochemicals produced by sorghum plants can decrease soil pH and increase the levels of available nitrogen and phosphorus, which can promote plant growth [22]. Liu et al. (2019) investigated the allelopathic effects of extracts from *Eupatorium adenophorum* on soil chemical properties and found that these extracts can increase soil organic matter content and improve the availability of phosphorus and potassium [23]. Zhang et al. (2019) studied the allelopathic effects of root exudates from wheat plants on soil chemical properties and found that these compounds can increase soil pH and the availability of nitrogen and phosphorus, which can promote plant growth [24]. According to Ali et al. (2019), the production of allelopathic chemicals by black nightshade plants can result in a reduction of soil pH, as well as an increase in the levels of available phosphorus and organic matter [25].
These studies suggest that allelochemicals can have diverse effects on the chemical structure of soil, which can depend on the specific allelochemicals involved, the concentration of these chemicals, and the soil properties and plant species present. Further research is needed to better understand the mechanisms involved in these interactions and to develop strategies for harnessing the positive effects of allelopathy on soil chemical properties and plant growth.

2.7 Allelochemicals can modify the soil profile:

Allelochemicals have the potential to modify the soil profile by altering soil properties such as texture, structure, organic matter content, and nutrient availability. For example, some allelochemicals may increase soil organic matter content by promoting the growth and activity of soil microorganisms, while others may decrease soil pH or alter soil nutrient availability.
One study by Li et al. (2015) found that allelochemicals released by the invasive plant *Ageratina adenophora* could modify the soil profile by increasing soil porosity, reducing soil bulk density, and enhancing soil water retention [8]. In a study conducted by Bano et al. (2016), it was revealed that the allelochemicals produced by *Parthenium hysterophorus* plants possess the ability to modify soil physical properties. These changes include a decrease in soil bulk density, as well as an increase in both soil water-holding capacity and aggregate stability. Moreover, the presence of allelochemicals can also have an impact on the composition and activity of soil microbial communities, resulting in further effects on soil properties and the overall soil profile. However, it's worth noting that the allelopathic effects of plant-produced chemicals on soil properties and the soil profile are complex and depend on multiple factors such as the type and concentration of allelochemicals, the soil properties, and the plant species involved [26].
Overall, while allelochemicals can have both positive and negative effects on soil properties and the soil profile, further research is needed to fully understand the complex mechanisms involved and to develop strategies for harnessing the potential benefits of allelochemicals while minimizing any negative impacts.

3. CONCLUSION

In conclusion, allelochemicals play an important role in regulating soil properties and ecosystem dynamics. The studies reviewed here demonstrate that allelopathy can have both positive and negative effects on soil microbial communities, nutrient availability, and plant growth, depending on the type and concentration of allelochemicals and the plant species involved. The ecological implications of allelopathy are complex and varied, but it is clear that these compounds have the potential to influence agricultural practices and ecosystem functioning in a variety of ways. As such, further research is needed to better understand the mechanisms and ecological consequences of allelopathy, and to identify ways to harness its potential benefits while mitigating its negative impacts.

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