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Degraded Forest Land Soil Microbial Community Structure Improvement Techniques and Their Ecological Effects

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Abstract

The structure of soil microbial communities in degraded forest lands is crucial for ecosystem functions. This study focuses on the improvement techniques for soil microbial community structures in degraded forest lands and discusses their ecological effects. By analyzing the impacts of different improvement techniques on soil microbial diversity, community composition, and ecosystem service functions, the ecological benefits of these techniques are revealed. The research finds that the addition of biochar and the inoculation of mycorrhizal fungi can significantly enhance soil microbial diversity, improve soil fertility, and strengthen ecosystem stability.

Keywords

Degraded forest land; Soil microbes; Improvement techniques; Ecological effects; Ecological restoration

Introduction

Soil microbial communities are key biological components of ecosystems, playing a vital role in soil fertility, nutrient cycling, and ecosystem stability. With increasingly severe forest degradation, soil microbial community structure is significantly impacted, leading to a gradual decline in ecosystem function. Exploring effective technologies for improving soil microbial community structure and assessing their ecological effects are of significant theoretical and practical importance for restoring the ecosystem function of degraded forests and promoting sustainable ecological development.

1. Screening and application of improved technologies

In the process of improving the soil microbial community structure of degraded forest land, technology screening and application are key links. Biochar addition technology has attracted much attention due to its significant improvement on soil physicochemical properties. Biochar is rich in microporous structure and abundant carbon source, which can provide a stable habitat and abundant nutrients for soil microorganisms (Liu, Zhang, & Li, 2022). After its addition, the aeration and water retention capacity of the soil are improved, creating favorable conditions for the growth and reproduction of microorganisms. The loose structure of biochar helps to improve the formation of soil aggregates, further promoting the increase of microbial community diversity. The adsorption performance of biochar can effectively reduce the bioavailability of heavy metals and organic pollutants in the soil, reduce the stress on microorganisms, and thus provide a guarantee for the healthy growth of microbial communities.

Mycorrhizal fungi inoculation technology is another effective improvement method. Mycorrhizal fungi form a

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symbiotic relationship with plant roots, which can significantly enhance the plant's ability to absorb nutrients from the soil, especially key nutrients such as phosphorus and nitrogen. Through the mycelial network of mycorrhizal fungi, plant roots can obtain nutrients from the soil more extensively, thereby promoting plant growth and development. The mycelium of mycorrhizal fungi can secrete a variety of enzymes and organic acids, which can decompose organic matter in the soil and release nutrients that can be used by microorganisms, thereby promoting the activity and diversity of soil microbial communities (Chen, Zhao, & Wang, 2021). The symbiotic relationship of mycorrhizal fungi can also enhance the plant's resistance to pathogens, reduce the occurrence of diseases, and further maintain the health and stability of the soil ecosystem.

Organic material addition technology provides abundant carbon and energy sources for microorganisms by increasing soil organic matter content. During the decomposition of organic materials, microorganisms convert them into stable organic matter such as humus. This process not only increases the soil's organic carbon reserves but also provides a continuous supply of nutrients for the microbial community. The addition of organic materials also improves the soil's physical structure, increasing porosity and aeration, which is beneficial for microbial activity and reproduction. The various nutrients released during the decomposition of organic materials, such as nitrogen, phosphorus, and potassium, can meet the growth needs of microorganisms, promoting rapid expansion and increased diversity of the microbial community.

2. The impact of soil improvement techniques on soil microbial community structure

In the process of soil improvement of degraded forest land, biochar addition, mycorrhizal fungi inoculation and organic material addition technologies have shown significant characteristics. As a porous material, biochar is characterized by improving soil physical structure, increasing porosity and permeability, and providing a more suitable habitat for microorganisms (Li, Zhang, & Liu, 2023). At the same time, biochar is rich in minerals and organic carbon, which can regulate soil pH and supplement nutrients, promote microbial diversity and increase the abundance of beneficial microorganisms (such as bacteria and fungi), and help decompose soil organic matter, cycle nutrients and inhibit pathogens.

Mycorrhizal fungi inoculation technology expands the absorption range of plant roots and enhances their ability to acquire nutrients and water by forming a symbiotic relationship with them. This symbiotic relationship not only promotes plant growth but also provides attachment sites and nutrient sources for other microorganisms through the mycelium, increasing the diversity and complexity of the microbial community. Mycorrhizal fungi can promote the dissolution and absorption of phosphorus in the soil and, in synergy with other microorganisms, accelerate the decomposition of organic matter, releasing more nutrients for plant use and enhancing soil nutrient conversion efficiency.

Organic material addition technology mainly includes compost, green manure, etc., which increases the soil organic matter content and provides microorganisms with abundant carbon and energy sources. During the decomposition process, these materials release a large amount of organic acids, amino acids and sugars, which directly provide nutrients for microorganisms and improve the chemical properties and physical structure of the soil (Wang, Zhao, & Sun, 2024). With the decomposition of organic materials, the soil microbial community structure is optimized, metabolic activities are enhanced, the circulation and transformation of nutrients in the soil are promoted, the soil water retention and aeration are improved, and the stability and resilience of the soil ecosystem are enhanced.

3. Ecological Effects Assessment of Improved Technologies

Techniques for improving the soil microbial community structure in degraded forest land have shown a significant promoting effect on ecosystem function restoration. Biochar addition technology improves soil physical structure, increases soil porosity and aeration, and provides a more suitable living environment for microorganisms. This technology also optimizes the living conditions of the microbial community by adsorbing harmful substances in the soil and reducing soil acidity. With the improvement of the soil environment, soil microbial diversity significantly increases, the relative abundance of beneficial microorganisms increases, and the microbial community structure gradually develops in a healthier direction. This optimization of the microbial community structure not only enhances the stability of the soil ecosystem but also strengthens the soil microorganisms' ability to transform nutrients, promoting the decomposition of organic matter and nutrient cycling in the soil. The addition of biochar also improves the soil's water retention capacity, reduces water evaporation, further improves soil moisture conditions, and provides a more sufficient water supply for plant growth.

Mycorrhizal fungi inoculation technology significantly enhances the plant's ability to absorb nutrients from the soil by forming a symbiotic relationship with the plant roots. The mycelial network of mycorrhizal fungi can expand the absorption range of plant roots and improve the plant's efficiency in acquiring key nutrients such as phosphorus and nitrogen from the soil. The application of this technology not only promotes plant growth, but also provides rich carbon sources and nutrients for soil microorganisms through the increase of plant root exudates, further promoting the growth and reproduction of soil microbial communities (Tan, Zhao, & Li, 2023). With the improvement of plant growth and the optimization of soil microbial community structure, the nutrient cycle in the ecosystem is accelerated and soil fertility is significantly improved. Mycorrhizal fungi inoculation also enhances the plant roots' resistance to pathogens, reduces the incidence of plant diseases, and thus improves the health level and stability of the ecosystem. The application of this technology provides important biotechnological support for the restoration of degraded forest ecosystems and helps to gradually restore ecosystem functions.

Organic material addition technology provides microorganisms with abundant carbon sources and nutrients by introducing a large amount of organic matter into the soil. The application of this technology significantly increases the soil organic matter content and improves the physical and chemical properties of the soil. With the increase of soil organic matter content, the activity of soil microorganisms is significantly improved, and the microbial community structure is more complex and diverse. The decomposition process of organic materials not only releases a large amount of nutrients that can be absorbed and utilized by plants, but also promotes the metabolic activities of microorganisms in the soil, further accelerating the decomposition of organic matter and the cycling of nutrients in the soil (Liu, Sun, & Zou, 2022). The application of this technology also improves the aggregate structure of the soil, enhances the water retention and permeability of the soil, and provides a better environment for the growth of plant roots. The application of organic material addition technology also increases the soil ecosystem's resistance to environmental stress by increasing the diversity of soil microorganisms, and enhances the stability and sustainability of the ecosystem. The realization of these ecological effects provides an important material basis and technical support for the restoration of degraded forest ecosystems, and promotes the gradual restoration and improvement of ecosystem functions.

4. Conclusions and Prospects of Techniques for Improving the Soil Microbial Community Structure of Degraded Forest Land

Techniques for improving the soil microbial community structure in degraded forest land have demonstrated significant potential for ecosystem function restoration. Techniques such as biochar addition, mycorrhizal fungal inoculation, and organic material addition provide favorable conditions for microbial community growth and reproduction by improving soil physical, chemical, and biological properties. The application of these techniques not only increases soil microbial diversity but also optimizes the composition of the microbial community, increasing the relative abundance of beneficial microorganisms. This improvement in microbial community structure further promotes soil fertility enhancement, accelerates nutrient cycling, and strengthens the ecosystem's resistance to environmental stresses. These ecological effects provide important theoretical support and practical guidance for the ecological restoration of degraded forest land.

Based on the current research, future work should focus on the optimization and improvement of improvement technologies. Although the existing improvement technologies have achieved certain results, there are still some limitations. Some technologies are expensive, which limits their application in large-scale ecological restoration; some technologies have a narrow scope of application and are difficult to adapt to different types of degraded forest land. Future research needs to further explore low-cost, efficient and widely applicable improvement technologies. The long-term ecological effects of improvement technologies also need to be monitored and evaluated more deeply (Wang, Li, & Zhou, 2022). Current research focuses on the observation of short-term effects, while the restoration of ecosystem functions is a long-term process that requires long-term follow-up studies to comprehensively evaluate the continuous impact of improvement technologies on soil microbial community structure and ecosystem functions. Through long-term monitoring, we can better understand the stability and durability of improvement technologies under different environmental conditions and provide a more scientific basis for ecological restoration.

Looking to the future, research and practice on ecological restoration of degraded forest land will face new opportunities and challenges. With the cross-integration of multiple disciplines such as ecology, soil science and microbiology, soil microbial community structure improvement technology is expected to be further developed. Combined with gene editing technology, more targeted microbial strains can be developed for ecological restoration of specific degraded forest land. With the intensification of global climate change, degraded forest land ecosystems are facing more complex environmental pressures. Future ecological restoration work needs to consider the ecosystem's own recovery capacity and combine climate change adaptation measures to formulate more scientific and reasonable restoration strategies. The success of ecological restoration depends not only on technological progress, but also on policy support and social participation. By strengthening policy guidance and public education on ecological restoration, the whole society can pay more attention to the ecological restoration of degraded forest land and promote the smooth development of ecological restoration work (Zhang, Liu, & He, 2023). Research on the improvement technology of soil microbial community structure of degraded forest land and its ecological effects will play a more important role in future ecological restoration work and provide strong support for the sustainable development of ecosystems.

5. Conclusion

Techniques for improving the soil microbial community structure of degraded forest land are crucial for the restoration of ecosystem functions. Technologies such as biochar addition, mycorrhizal fungal inoculation, and organic material addition significantly enhance soil microbial diversity and strengthen ecosystem stability by improving soil physical, chemical, and biological properties. Future research should further optimize these techniques, reduce application costs, expand their applicability, and conduct long-term ecological effect monitoring. Combining multidisciplinary research to develop more targeted improvement strategies, along with strengthened policy support and social participation, will facilitate the smooth implementation of ecological restoration work in degraded forest land and contribute to the sustainable development of ecosystems.

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