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Research Progress on the Nitrogen Control Effect of Alfalfa in Agricultural Runoff Mediated by Soil Microorganisms

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Abstract

This paper systematically reviews the research on the nitrogen control effect of alfalfa in agricultural runoff mediated by soil microorganisms. It deeply analyzes the interaction between alfalfa and soil microorganisms, elaborates on the mediating mechanism of microorganisms, comprehensively summarizes the related research achievements, objectively analyzes the existing problems, and prospects for future research directions. The aim is to provide a comprehensive and in-depth theoretical basis for the control of agricultural non-point source pollution and to promote the optimization and sustainable development of nitrogen management in agricultural ecosystems.

Keywords

Alfalfa; Soil Microorganisms; Agricultural Runoff Nitrogen; Control Effect; Research Progress.

1. Introduction

In agricultural production, nitrogen is a key nutrient to ensure crop yields, but excessive application of nitrogen fertilizers and unreasonable agricultural management measures lead to a large amount of nitrogen entering surrounding waters through agricultural runoff. This not only waste resources of nitrogen fertilizers but also causes serious environmental problems, such as eutrophication of water bodies, leading to excessive algal growth, reduced dissolved oxygen, deterioration of the living environment of aquatic organisms, and ultimately destroying the balance of the entire water ecosystem[1]. In addition, agricultural runoff nitrogen pollution also threatens drinking water safety and poses potential hazards to human health. Alfalfa, as a widely cultivated leguminous plant, due to its good ecological functions, especially in nitrogen cycling and soil and water conservation, as well as its close relationship with soil microorganisms, provides a new idea and approach to solving the problem of agricultural runoff nitrogen pollution.

The purpose of this study is to deeply and systematically reveal the control effect and intrinsic mechanism of alfalfa on agricultural runoff nitrogen mediated by soil microorganisms. By fully analyzing the complex relationship between alfalfa and soil microorganisms, it is aimed to clarify the key mediating role of microorganisms in this process, providing a solid theoretical foundation for the scientific management of nitrogen in precision agriculture[2]. In practical terms, it is helpful to develop efficient and environmentally friendly agricultural runoff nitrogen

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control technologies based on alfalfa cultivation, reduce the use of chemical fertilizers, lower agricultural non-point source pollution, promote the green and sustainable development of agriculture, achieve the harmonious coexistence of agricultural production and ecological protection, and has important and far-reaching significance for safeguarding the health of agricultural ecosystems and the quality and safety of agricultural products.

2. The Interaction between Alfalfa and Soil Microorganisms

2.1. The Biological Characteristics of Alfalfa And its Influence on Soil Environment

Alfalfa is a perennial leguminous forage grass with strong vitality and adaptability. Its root system is extremely developed, with the main root extending several meters into the soil and many lateral roots distributed widely. This root structure not only firmly fixes the soil, effectively preventing soil erosion, but also improves the physical structure of the soil through the interweaving and growth of the roots, increases the porosity of the soil, improves the aeration and permeability of the soil, and creates a good environment for the survival and activity of soil microorganisms. In addition, alfalfa has a unique symbiotic nitrogen fixation capacity, which can convert nitrogen gas in the air into plant available ammonium nitrogen through symbiotic relationships with rhizobia, not only meet its own growth needs but also increase the nitrogen content in the soil, provide abundant nitrogen sources for subsequent crops, and reduce the use of chemical fertilizers. During its growth, alfalfa also secretes a large amount of root exudates to the rhizosphere environment, including sugars, amino acids, organic acids, and various other organic substances[3-4]. These exudates provide a rich carbon source and energy for rhizosphere microorganisms, attracting a large number of microorganisms to aggregate in the rhizosphere, thereby significantly changing the composition and structure of the rhizosphere microbial community.

2.2. The Influence of Soil Microorganisms on the Growth and Function of Alfalfa

Soil microorganisms play an indispensable role in the growth and development and the functioning of alfalfa. Rhizosphere plant growth-promoting bacteria can produce various plant hormones, such as auxins, cytokinins, and gibberellins, which can promote the growth and development of alfalfa roots, increase the length, surface area, and number of root hairs of the roots, and thereby improve the absorption capacity of alfalfa for soil nutrients and water. In addition, some rhizosphere plant growth-promoting bacteria can produce iron chelators, increase the availability of iron elements, and help alfalfa resist iron stress[5]. Mycorrhizal fungi form symbiotic bodies with alfalfa roots, the mycelium of which can extend to a much greater distance in the soil, expanding the absorption range of the roots, especially enhancing the uptake capacity of trace elements such as phosphorus, zinc, and copper. At the same time, mycorrhizal fungi can enhance the stress resistance of alfalfa, improve its resistance to drought, high temperature, pests and diseases, and other abiotic stresses. Soil microorganisms also participate in the decomposition and transformation of organic matter in the soil, decomposing complex organic matter into simple inorganic nutrients such as nitrogen, phosphorus, and potassium, providing sufficient nutrition for the growth of alfalfa, maintaining the stability and sustainability of soil fertility.

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3. The Mechanism of Soil Microorganisms Mediating the Control of Agricultural Runoff Nitrogen by Alfalfa

3.1. Soil Microorganisms' Regulation of Nitrogen Transformation Processes

Soil microorganisms participate in multiple key processes of the nitrogen cycle and play an important role in the transformation and migration of nitrogen. Ammonification is an important process in which organic nitrogen is converted into ammonium nitrogen. Ammonification bacteria can use organic nitrogen compounds as carbon and nitrogen sources and decompose them into ammonium nitrogen released into the soil through a series of enzyme reactions, providing plant available nitrogen. Nitrogen fixation is the process by which nitrate bacteria convert ammonium nitrogen into nitrate nitrogen, including ammonia-oxidizing bacteria and nitrite-oxidizing bacteria, which oxidize ammonium nitrogen stepwise into nitrite and nitrate under aerobic conditions. Although nitrate nitrogen is one of the plant easily absorbed nitrogen forms, it is highly mobile in the soil and is prone to be lost with agricultural runoff. Denitrification is the process in which denitrifying bacteria reduce nitrate nitrogen to nitrogen gas, nitrous oxide, and other gaseous nitrogen compounds in anaerobic conditions, returning them to the atmosphere. This process effectively reduces the content of nitrate nitrogen in the soil and reduces the risk of nitrogen loss with runoff. In the soil of alfalfa cultivation, the structure and activity of the microbial community will change significantly, which will affect the rate and direction of nitrogen transformation processes. For example, the microenvironment characteristics of the rhizosphere of alfalfa, such as the types and quantities of root exudates, oxygen concentration, and pH, can affect the growth and metabolism of ammonia-oxidizing bacteria, nitrate-oxidizing bacteria, and denitrifying bacteria, and thus regulate the transformation and migration of nitrogen.

3.2. The Influence of Alfalfa-microbe Interaction on Nitrogen Adsorption and Fixation

Alfalfa roots and soil microorganisms form a close interaction, which plays an important role in the adsorption and fixation of nitrogen. During the growth process, alfalfa roots secrete a large amount of organic substances to the rhizosphere, which not only provide a source of nutrition for soil microorganisms but also attract specific microorganisms to aggregate in the rhizosphere, forming a unique rhizosphere microbial community. Rhizosphere microorganisms increase the cohesion between soil particles through the secretion of extracellular polymers and promote the formation of soil aggregates. Soil aggregates have a large specific surface area and rich pore structure, which have strong adsorption and fixation capacity for nitrogen and can effectively reduce the migration of nitrogen in runoff. In addition, there is a synergistic effect between microorganisms and alfalfa roots, which enhances the physical and chemical adsorption of soil to nitrogen by changing the surface charge properties and pore structure of the soil. For example, some microorganisms can secrete polysaccharides, which can combine with soil particles and nitrogen to form stable complexes, thereby improving the adsorption and fixation capacity of soil to nitrogen. At the same time, the growth and metabolic activities of alfalfa roots also affect the aeration and water conditions of the soil, thereby affecting the activity of microorganisms and the adsorption and fixation process of nitrogen.

4. Research Methods and Achievements of the Control Effect of Alfalfa on Agricultural Runoff Nitrogen

Field experiments are one of the important means to study the control effect of alfalfa on agricultural runoff nitrogen. By setting different alfalfa planting patterns (such as sole cropping,

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intercropping, and mixed cropping), planting years, and fertilizer treatments in the experimental plots, using runoff plots or long-term monitoring stations, collecting agricultural runoff samples under natural rainfall conditions. When collecting runoff samples, it is necessary to accurately record the rainfall amount, rainfall time, runoff generation time, and runoff volume, and analyze and measure the nitrogen content and form (such as ammonium nitrogen, nitrate nitrogen, organic nitrogen, etc.) in runoff samples in a timely manner. At the same time, it is also necessary to monitor and analyze the soil properties, alfalfa growth status, and soil microbial community structure in the experimental plots, in order to comprehensively understand the influence factors of the control effect of alfalfa on agricultural runoff nitrogen. Indoor simulation experiments are conducted under artificial controllable conditions, using simulation rainfall facilities and runoff collection systems, precisely controlling environmental factors such as rainfall intensity, soil moisture, and temperature, studying the control effect of alfalfa and soil microorganisms on runoff nitrogen under different conditions. Indoor simulation experiments can exclude the interference of natural environmental factors, and deeply study the influence of specific factors on the control mechanism of the alfalfa-microbe system. In addition, molecular biological techniques such as high-throughput sequencing and real-time fluorescence quantitative PCR have also been widely used in the study of the control effect of alfalfa on agricultural runoff nitrogen. High-throughput sequencing technology can comprehensively analyze the composition and structure changes of the soil microbial community, and real-time fluorescence quantitative PCR technology can quantitatively detect the expression levels of functional genes related to nitrogen transformation, revealing the mediating mechanism of microorganisms from the microscopic level.

A large number of studies have shown that planting alfalfa can significantly reduce the nitrogen loss in agricultural runoff. Compared with traditional crop planting, the total nitrogen, ammonium nitrogen, and nitrate nitrogen content in the runoff from alfalfa fields is significantly reduced, and the control effect is remarkable. It is found that the longer the planting period of alfalfa, the better the control effect on agricultural runoff nitrogen, which may be related to the growth and development of the alfalfa root system and the gradual stabilization of the soil microbial community. In different planting patterns, the control effect of alfalfa in intercropping or mixed cropping with other crops is better than that of sole alfalfa, which is due to the complementary root systems of different crops and the synergistic effect of microbial communities, which can better promote the absorption and transformation of nitrogen. Soil microorganisms play a key mediating role in the control of agricultural runoff nitrogen by alfalfa. The diversity and activity of rhizosphere microbial communities in alfalfa are significantly higher than those in non-rhizosphere soil, and the number and expression levels of functional genes related to nitrogen transformation also change significantly. For example, the number of ammonia-oxidizing bacteria, nitrate-oxidizing bacteria, and denitrifying bacteria in rhizosphere soil increases, and the expression of related functional genes is upregulated, indicating that the role of microorganisms in nitrogen transformation is enhanced. In addition, environmental factors also have a significant impact on the control effect of the alfalfa-microbe system on nitrogen. Factors such as precipitation intensity, soil texture, and fertilizer application affect the nitrogen loss in agricultural runoff by changing soil moisture conditions, microbial activity, and the growth status of alfalfa. In heavy rainfall, the soil nitrogen is easily washed into runoff, and the soil-binding and nitrogen intercepting effect of alfalfa roots and microorganisms are weakened, resulting in an increase in runoff nitrogen loss. Soil with looser texture has weaker adsorption and fixation capacity of nitrogen, which also increases the risk of nitrogen loss in runoff.

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5. Research Conclusion

Although some research results have been achieved in the control effect of alfalfa on agricultural runoff nitrogen mediated by soil microorganisms, there are still some shortcomings. Firstly, the research on the molecular mechanism is not deep enough, and the understanding of the signal transduction, gene expression regulation, and key metabolic pathways between alfalfa and soil microorganisms is still very limited. It is necessary to further use multi-omics technologies (such as transcriptomics, proteomics, and metabolomics) for in-depth exploration. Secondly, there are significant differences in research among different ecological regions, and there is a lack of systematicity and comprehensiveness. More cross-regional research is needed to clarify the control effect of alfalfa on agricultural runoff nitrogen and the mediating mechanism of microorganisms under different soil and climatic conditions, so as to formulate more accurate agricultural non-point source pollution prevention and control strategies. In addition, the current research mainly focuses on the control effect and mechanism of alfalfa on agricultural runoff nitrogen, and there is little research on the integrated optimization of alfalfa cultivation with other agricultural management measures (such as rational fertilization, irrigation management, soil and water conservation measures, etc.). In the future, more research in this aspect should be strengthened to form a complete technology system for the control of agricultural runoff nitrogen.

This study comprehensively elaborates on the control effect and intrinsic mechanism of alfalfa on agricultural runoff nitrogen mediated by soil microorganisms. Through complex interactions, alfalfa and soil microorganisms play an important role in nitrogen transformation, adsorption, and fixation, effectively reducing the nitrogen loss in agricultural runoff. However, in order to give full play to the role of alfalfa in the control of agricultural non-point source pollution, further research is needed on its interaction mechanism with soil microorganisms, strengthen the research on different ecological regions, and optimize the integration with other agricultural management measures. Through these studies, it is expected to provide more scientific, comprehensive theoretical basis and technical support for the efficient management of nitrogen in agricultural ecosystems and the effective control of agricultural non-point source pollution, and promote the sustainable development of agriculture.

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