学位論文の要旨

Abstract of Thesis

研究科 School	Graduate School of Environmental and Life Science
専　攻 Division	Division of Environmental Science
学生番号 Student No.	77D21151
氏　名 Name	NGO THUY AN

学位論文題目 Title of Thesis（学位論文題目が英語の場合は和訳を付記）

Sustainable Practice for Water-Scarce Agriculture: Enhancing Soil Water Retention and Plant Growth Efficiency with Cellulose Nanofibers

（持続可能な節水型農業の実践：セルロースナノファイバーによる土壌保水と植物生育効率の向上）

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Water scarcity and soil degradation pose significant challenges to sustainable agriculture and food security worldwide. Many regions are experiencing high water stress, where the demand for water exceeds the available amount during certain periods, or where poor quality restricts its use. Groundwater levels are declining rapidly due to over-extraction, primarily driven by agricultural needs. Climate change, unsustainable extraction practices, population growth, and pollution are further exacerbating this crisis, leading to reduced crop yields and heightened food insecurity. Addressing water scarcity and ensuring food security requires innovative and sustainable agricultural practices.

Recent decades have seen an explosion of research on innovative solutions to address water scarcity and soil degradation, ensuring sustainable food production. One such innovation is the development and use of superabsorbent polymers (SAPs) in agriculture. Among these polymers, cellulose nanofibers (CNF), derived from natural cellulose, stand out due to their unique properties and potential. CNF are increasingly recognized for their outstanding water retention capabilities, being biodegradable, sustainable, and environmentally friendly. Their ability to significantly enhance soil moisture retention makes them a promising candidate for improving water efficiency in agriculture. This study explores the properties, applications, benefits, challenges, and prospects of CNF in water-scarce agricultural settings.

This PhD thesis, titled "Sustainable Practice for Water-Scarce Agriculture: Enhancing Soil Water Retention and Plant Growth Efficiency with Cellulose Nanofibers," investigates the use of cellulose nanofibers (CNF) as an innovative solution to improve soil water retention and plant efficiency in water-scarce regions. By addressing key research gaps and leveraging the unique properties of CNF, this research aims to optimize their application in agriculture, assess their effectiveness under various environmental conditions, and ensure their safe and sustainable use.

The study had several objectives: Firstly, it seeks to investigate how different CNF preparation methods significantly affect its structure, leading to variations in water absorption efficiency. By identifying the optimal preparation methods, the research aims to achieve higher efficiency in CNF application. Secondly, the study will examine various environmental factors and their mechanisms that impact the water absorption efficiency of CNF. This includes evaluating the influence of irrigation water quality, soil characteristics, and understanding the intrinsic water absorption mechanism of CNF. These insights will provide a comprehensive understanding of how to maximize the

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performance of CNF under diverse agricultural conditions. Another crucial objective is to assess the longevity of CNF in soil by studying its efficiency in absorbing water over multiple wet and dry cycles. This involves determining the rate of reduction in water absorption capacity with each cycle, which is essential for estimating the durability and re-application frequency of CNF in agricultural settings. Additionally, the research will provide evidence of the effectiveness of CNF on soil health through the promotion of macro-aggregate formation and stability. This will help demonstrate the potential of CNF to improve soil structure and resilience. Furthermore, the research will evaluate the impact of CNF on germination and plant growth under various water regimes, ranging from adequate to deficit irrigation. These evaluations will help confirm the non-phytotoxic nature of CNF, while also demonstrating its support for plant growth and irrigation water use efficiency under deficit irrigation regimes. This positions CNF as a potential solution to mitigate water scarcity and improve crop resilience.

The methodology included laboratory and greenhouse experiments involving different CNF dosages, soil types, and irrigation conditions. In the first study, CNF was shown to significantly improve soil water retention and aggregate stability. CNF dried at 5°C was the most effective at water absorption, enhancing soil water content by up to 98% and prolonging water retention by 22 days in paddy soils. Fourier-transform infrared spectroscopy and scanning electron microscopy confirmed that CNF absorbed water due to their hydrophilic functional groups and morphological structure. CNF also increased macro-aggregate formation by up to 48% and 59% in masa and paddy soils, respectively.

The second study demonstrated that CNF increased plant-available water (PAW) by up to 110% in sandy soils and 88% in silty loam soils. CNF improved germination and plant growth under water stress, with germination index enhancements of up to 163% at moderate water stress (I50) and up to 214% at severe water stress (I25). CNF addition helped plants maintain similar heights and weights under water-stressed conditions compared to full irrigation, while using 50% less water. Irrigation water use efficiency (IWUE) also significantly increased, with enhancements of up to 169% at moderate water stress (I50) and 120% under severe water stress (I25) at 1% CNF concentration.

The findings highlight the potential of CNF as a multifaceted soil amendment, offering practical solutions for water conservation, soil health improvement, and increased crop resilience in water-scarce regions. CNF’s ability to retain water and promote soil stability makes it a valuable tool for sustainable agricultural practices, particularly in regions facing severe environmental challenges such as arid and semi-arid areas.

Future research will focus on developing environmentally friendly and cost-effective methods for CNF production from agricultural residues, evaluating CNF’s role as a nutrient carrier, and testing CNF’s effectiveness in enhancing crop resistance to drought, alum contamination, and salinity. These efforts aim to further advance the application of CNF in agriculture, contributing to more resilient and sustainable farming systems.