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PERSPECTIVE

Innovative approaches to improving water use efficiency in forest ecosystems

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Water scarcity and inefficient water management in forest ecosystems have become pressing concerns globally due to the increasing impacts of climate change, deforestation, and land degradation. Forests play a crucial role in regulating the water cycle and maintaining ecological balance. Therefore, improving water use efficiency (WUE) in forest ecosystems is vital to sustain their ecological services. This article examines innovative approaches that enhance water use efficiency in forests, focusing on hydrological practices, genetic improvements, ecosystem restoration, and technological innovations. By incorporating these approaches, forest management practices can be adapted to improve water conservation, resilience to droughts, and overall ecosystem health. Ultimately, enhancing WUE is a strategic response to mitigate the effects of water scarcity while ensuring the sustainability of forest ecosystems in the face of climate change.

Keywords: Water use efficiency, Forest ecosystems, Climate change, Water management, Ecosystem restoration, Hydrological practices, Drought resistance, Sustainability, Forest management, Technological innovation.

Introduction

Water Use Efficiency (WUE) refers to the ratio of beneficial water outputs to water inputs, often evaluated as the amount of biomass or ecological productivity produced per unit of water consumed. In forest ecosystems, WUE is an essential parameter for understanding how forests interact with the water cycle and how their water consumption affects surrounding environments. As global temperatures rise and precipitation patterns become more erratic, forests are increasingly threatened by water shortages, reduced soil moisture, and prolonged droughts. Forest ecosystems are essential for the global water cycle, providing various services such as groundwater recharge, carbon sequestration, soil stabilization, and habitat for biodiversity. However, the ability of these ecosystems to provide such services is often compromised by inefficient water use. Improving WUE in forest ecosystems is critical not only for maintaining forest health but also for ensuring that they can continue to perform their role in mitigating climate change and supporting human livelihoods. This explores innovative approaches to improving WUE in forest ecosystems. These approaches include new hydrological management practices, genetic advancements in tree species, ecosystem restoration efforts, and cutting-edge technologies such as remote sensing and precision forestry (Arain MA, et al. 2022). These strategies aim to improve water conservation, increase forest resilience to climate variability, and enhance the sustainability of forest ecosystems in the long term.

Description

Hydrological management is one of the key components of improving WUE in forest ecosystems. Effective management of water resources within forests is necessary to address challenges such as water scarcity and inefficient water use. Several hydrological

practices can enhance WUE, including controlled burning, afforestation, and reforestation of catchment areas, and the installation of water-efficient irrigation systems for managed forests. In forest ecosystems, fire plays a complex role in both maintaining and disrupting the water cycle. While fires can help restore nutrients to the soil, promote biodiversity, and reduce the risk of catastrophic wildfires, they can also disrupt the natural water balance. Controlled or prescribed burning is a management strategy where fires are intentionally set under controlled conditions to remove excess vegetation, reduce fuel load, and improve water retention in the soil (Heilman KA, et al. 2021). By reducing the occurrence of uncontrolled wildfires, this practice ensures that forests can better manage their water resources. Afforestation and reforestation efforts in degraded watersheds help restore natural hydrological cycles by increasing water retention in the soil and enhancing groundwater recharge. Planting trees in areas that have suffered from deforestation or land degradation provides the opportunity to improve local climate conditions and water availability, thereby improving WUE. These strategies are particularly beneficial in areas that experience frequent droughts or reduced rainfall.

For forests that are managed for timber production or other purposes, water-efficient irrigation systems can ensure that trees receive adequate moisture while minimizing water wastage. Irrigation techniques such as drip irrigation and subsurface irrigation can be particularly effective in improving WUE, as they deliver water directly to the root zone, reducing evaporation losses. These systems are especially valuable in regions where water is scarce but forests still need to be actively managed for commercial or restoration purposes (Lu F, et al. 2018). Genetic research is playing an increasingly important role in enhancing WUE in forest ecosystems. By identifying tree species or populations that exhibit traits associated with improved water efficiency, forest managers can select and propagate these species to enhance the overall WUE of forests. Breeding trees with improved drought tolerance is one of the most promising approaches to increasing WUE in forest ecosystems. Through the use of genetic selection, it is possible to identify traits in tree species that allow them to survive and thrive under drought conditions. Such traits may include deeper root systems that allow trees to access water from deeper soil layers, reduced transpiration rates that help conserve water, and enhanced water storage capabilities.

Genetic modification techniques, such as CRISPR gene editing, can be used to enhance water use efficiency in forest species. By introducing genes that promote drought resistance or regulate water uptake and transpiration processes, genetic modification has the potential to create tree species that are better adapted to changing climate conditions and water-scarce environments. However, this approach must be carefully managed to ensure ecological balance and avoid unintended consequences (Peng SS, et al. 2014). Ecosystem restoration and conservation are key to improving WUE in degraded or overexploited forest regions. Forest restoration not only involves replanting trees but also enhancing soil structure, improving vegetation cover, and restoring ecological processes that are vital for water regulation. Soil moisture is a critical factor in determining the water availability to trees. Improved soil management practices such as mulching, the use of organic amendments, and the re-establishment of soil microbiomes help enhance soil moisture retention. Restoring soil health supports tree growth, increases water retention capacity, and ultimately improves WUE. Additionally, promoting biodiversity in forest ecosystems can also enhance soil structure and microbial diversity, which is beneficial for moisture retention. Riparian buffers, or vegetated areas near water bodies, play an essential role in controlling water flow, improving water quality, and supporting biodiversity. Restoring riparian buffers by planting native vegetation along rivers and streams can help improve WUE by increasing water infiltration, reducing soil erosion, and protecting water sources from contamination. Additionally, riparian buffers contribute to stabilizing stream flow during dry periods, thus enhancing the resilience of forest ecosystems to droughts (Battipaglia G, et al. 2013).

Conclusion

Innovative approaches to improving water use efficiency in forest ecosystems are essential for the long-term sustainability of these vital ecological systems. By employing a combination of hydrological practices, genetic advancements, ecosystem restoration, and technological innovations, forest managers can enhance the ability of forests to conserve water, increase resilience to climate variability, and continue to provide essential ecological services. As the challenges of climate change and water scarcity intensify, it

is crucial to adopt these strategies on a global scale to protect the health and functionality of forest ecosystems, ensuring they continue to support biodiversity, carbon sequestration, and vital water resources for generations to come. The integration of these innovative approaches offers a promising pathway toward achieving sustainable forest management practices that prioritize water use efficiency, restore degraded ecosystems, and enhance the adaptive capacity of forests in an uncertain climate future. By prioritizing water conservation and efficiency, forest ecosystems can play a crucial role in mitigating climate change, promoting biodiversity, and supporting livelihoods in a water-scarce world.

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Conflict of Interest

The authors declare no conflict of interest.

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