Highlights

Enhancing Nitrate Removal in Denitrifying Woodchip Bioreactors: A Comprehensive Analysis of Enhancement Strategies and Environmental Trade-offs

Reza Moghaddam[1,*] and Laura E. Christianson[2]

[1]Earth Sciences New Zealand
[2]Research Associate Professor, Department of Crop Sciences, University of Illinois at Urbana-Champaign
S-322 Turner Hall, Urbana, IL 61801, USA
*Corresponding author: reza.moghaddam@niwa.co.nz

Research Highlights

- **Comprehensive Systematic Review**: Systematic review of 70 studies evaluates enhancement strategies for woodchip bioreactors treating nitrate-contaminated water across multiple experimental scales and operational conditions.

- **Quantified Performance Enhancement**: Carbon supplementation achieves 5.1–8.6 g N/m^3/day removal rates while alternative media approaches reach 12.8–15.2 g N/m^3/day, representing substantial improvements over conventional woodchip systems.

- **Temperature Sensitivity Analysis**: Temperature sensitivity varies substantially among strategies (Q_{10} = 1.8–3.0), with aged woodchips showing greater temperature dependence than fresh materials, providing critical design guidance for climate-specific applications.

- **Economic Cost-Effectiveness**: Enhanced systems demonstrate cost-effectiveness ranging from \$10.56–86/kg N removed depending on strategy and operational conditions, with comprehensive lifecycle analysis and standardization to 2023 USD for accurate comparisons.

- **Environmental Impact Mitigation**: Comprehensive mitigation strategies address environmental trade-offs including greenhouse gas emissions, dissolved organic carbon leaching, and phosphorus dynamics through optimized hydraulic retention time (8–16 hours) and proper system design.

- **Comparative Economic Analysis**: Economic analysis reveals lifecycle considerations and comparative performance against conventional agricultural treatment options, including constructed wetlands (\$15–60/kg N) and precision nutrient management systems (\$5–25/kg N).

Practical Significance

This work provides the first standardized framework for comparing woodchip bioreactor enhancement strategies, enabling informed decision-making for water quality management applications. The comprehensive analysis addresses critical knowledge gaps in environmental trade-off assessment while providing practical implementation guidance for diverse stakeholder groups.