Mitigating Reactive Nitrogen Cascade Effects in Deltaic Wetland Systems Through Constructed Riparian Buffer Optimization Under Intensified Agricultural Runoff Regimes

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Abstract. Reactive nitrogen (Nr) accumulation in deltaic wetland ecosystems poses a critical threat to biogeochemical cycling, aquatic biodiversity, and downstream coastal eutrophication. This study investigates the efficacy of optimized constructed riparian buffer strips (CRBS) in intercepting Nr flux—specifically nitrate-nitrogen (NO_3^--N) and ammonium-nitrogen (NH_4^+-N)—under intensified agricultural runoff regimes in the Mekong Delta region. Using a combination of stable isotope tracing ($\delta^{15}N$), in-situ porewater sampling, and HYDRUS-2D vadose zone modelling, we quantified denitrification rates and Nr retention efficiency across five CRBS configurations. Results demonstrate that multi-strata native-species buffers achieving widths ≥35 m reduced total Nr export by 67.4% compared to monoculture grass strips. Microbial community profiling via 16S rRNA amplicon sequencing revealed significant enrichment of Candidatus Accumulibacter and Nitrosomonas lineages correlating with peak denitrification activity. These findings provide actionable design thresholds for wetland buffer policy in Southeast Asian deltaic agroecosystems.

Keywords: reactive nitrogen cascade, deltaic wetland biogeochemistry, constructed riparian buffer strips, agricultural nitrogen runoff, denitrification efficiency, HYDRUS-2D vadose zone modelling, stable isotope tracing $\delta^{15}N$, coastal eutrophication mitigation, Southeast Asian agroecosystems

Introduction

Reactive nitrogen (Nr) enrichment originating from intensified agricultural practices represents one of the most pervasive and structurally complex environmental stressors confronting deltaic wetland ecosystems in the twenty-first century. Unlike carbon cycling perturbations, which have benefited from decades of coordinated global monitoring, the nitrogen cascade—whereby a single Nr molecule sequentially degrades multiple environmental compartments, from soil nitrification through freshwater eutrophication to atmospheric nitrous oxide (N_2O) emission—remains insufficiently constrained at the landscape scale, particularly within monsoonal deltaic environments subject to dynamic hydrological pulses. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) 2024 assessment explicitly identified Nr loading as a principal driver of wetland functional degradation across tropical and subtropical low-elevation coastal zones, estimating that approximately 78% of deltaic wetland systems in South and Southeast Asia currently receive Nr inputs exceeding critical load thresholds by a factor of two or more. The biogeochemical consequences of chronic Nr enrichment in these settings are multifaceted. Elevated nitrate-nitrogen (NO_3^--N) concentrations promote hypoxic micro-niches within sediment porewater, suppressing methanotrophic and sulfate-reducing microbial guilds while simultaneously stimulating heterotrophic denitrifier populations in a manner that amplifies N_2O emission factors. Concurrently, ammonium-nitrogen (NH_4^+-N) accumulation in shallow inundated soils disrupts macrophyte stoichiometry and accelerates the competitive exclusion of native helophyte assemblages by invasive nitrophilous species, fundamentally restructuring the structural heterogeneity upon which deltaic avifauna and macroinvertebrate communities depend. These compound effects translate directly into diminished provisioning and regulating ecosystem service delivery at a time when deltaic communities face compounding pressures from sea-level rise, saltwater intrusion, and climate-driven monsoon intensification projected through the 2026–2050 planning horizon. Constructed riparian buffer strips (CRBS) have been widely proposed as cost-effective, nature-based solutions for intercepting Nr fluxes at the agricultural–wetland interface. However, critical knowledge gaps persist regarding the optimal structural configuration of CRBS under high-magnitude, episodic runoff pulses characteristic of monsoon-driven deltaic hydrology. Existing empirical datasets, predominantly derived from temperate row-crop contexts in North America and northern Europe, provide limited transferable guidance for tropical agroecosystem managers. In particular, the interactions among buffer width, vegetation strata complexity, hydraulic loading rate, and subsurface microbial community composition under Nr-enriched porewater conditions have not been systematically resolved for Southeast Asian deltaic settings. This paper addresses these gaps through an integrated field-experimental and numerical modelling framework applied across five structurally differentiated CRBS configurations in the Vietnamese Mekong Delta. The study first characterises Nr flux dynamics using stable isotope tracing and porewater geochemistry, then quantifies denitrification rates and Nr retention efficiency via HYDRUS-2D vadose zone simulation, and finally links Nr processing outcomes to subsurface microbial community structure resolved through 16S rRNA amplicon sequencing. The paper proceeds as follows: Section 2 describes the study sites, experimental design, and analytical methods; Section 3 presents the field-measured and modelled Nr retention results; Section 4 interprets microbial community drivers of denitrification performance; and Section 5 synthesises practical design thresholds and policy-relevant recommendations for CRBS implementation in tropical deltaic agroecosystems.

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