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# Sulfur-based denitrification as a driver of nitrate removal in an agriculturally influenced riparian corridor

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Sulfur cycling strongly influences redox dynamics in anoxic sediments and groundwater, yet its contribution to inorganic nitrogen removal in freshwater riparian corridors remains poorly constrained. In aquifers underlain by marine-derived sediments, sulfate supplied through mineral weathering may stimulate sulfate reducing bacteria (SRB), producing reduced sulfur compounds that can be subsequently oxidized by sulfide oxidizing bacteria (SOB) coupled to nitrate reduction. This sulfur-nitrogen coupling has the potential to enhance inorganic nitrogen removal in groundwater receiving elevated nitrate inputs. Here, we integrated stable sulfur isotopes ($SO_4^{2-}$-), nitrate isotopes ($NO_3^-$-$d^{15}N$ and -$d^{18}O$), 16S rRNA gene sequencing, and genome-resolved metagenomics to investigate sulfur-nitrogen interactions within groundwater receiving nitrate at concentrations approaching 20 mg-N $L^{-1}$- twice the U.S. EPA drinking water standard. Sulfur-based denitrifiers affiliated with the genera *Rhodoferax*, *Sulfuritalea*, and *Thiobacillus* were among the 40 most abundant taxa identified by amplicon sequencing. Metagenome-assembled genomes (MAGs) assigned to these taxa encoded genes associated with nitrate reduction (*narG*, *napA)* and sulfur oxidation (*soxB, fcc, sqr, dsrA*), indicating metabolic potential for sulfur-driven denitrification. At a riparian groundwater location where nitrate attenuation was greatest (<1 mg-N $L^{-1}$ from December 2023 to August 2024), sulfate concentrations declined from 95.92 to 53.51 mg-S $L^{-1}$ while $SO_4^{2-}$-$d^{34}S$ values increased from -18.04‰ to -12.52‰, consistent with microbial reduction of sulfate derived from weathering of marine shale. Concurrent enrichment in $NO_3^-$-$d^{15}N$ and $d^{18}O$ values with decreasing nitrate concentrations at these sites provide corollary evidence of nitrate reduction processes. Together, these geochemical and genomic signals suggest that sulfate reduction and subsequent oxidation of reduced sulfur compounds contribute to nitrate removal in this freshwater aquifer. Our findings indicate that sulfur-driven nitrate reduction may represent an underappreciated pathway for improving water quality in sulfate-rich riparian groundwater systems.