Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.37934

Headwater streams as hotspots of groundwater-derived greenhouse gas emissions in agricultural landscapes

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Reliable quantification of greenhouse gas (GHG) emissions from agricultural landscapes is required to inform effective climate mitigation strategies. Although CO_2 represents the largest share of riverine GHG fluxes in terms of magnitude, N_2O is of particular concern because of its high global warming potential and its role as the main ozone-depleting substance currently emitted. Agricultural soils are recognized as major sources of both gases, yet the contribution of small streams draining agricultural areas remains insufficiently constrained. Headwater streams, in particular, are still poorly understood with respect to their biogeochemical functioning, and have been referred to as an “Aqua Incognita”. Experimental evidence suggests that gas transfer between headwater streams and the atmosphere is frequently underestimated, implying that GHG emissions from small agricultural catchments may be overlooked. Given that headwater streams drain nearly 70% of the terrestrial surface, neglecting their role could introduce significant biases in global estimates of GHG emissions from terrestrial and freshwater systems.

This study examines the contribution of agricultural headwater streams to CO_2 and N_2O emissions. Dissolved CO_2 and N_2O were quantified along several streams and at multiple spatial scales in Brittany (France) using gas chromatography with electron capture detection (GC-ECD). These measurements were complemented by groundwater tracers, including radon (^222Rn) and dissolved silica (DSi), in order to determine the origin of CO_2 and N_2O. In addition, in situ gas tracer experiments were performed to assess air–water gas exchange rates using a continuous-flow membrane inlet mass spectrometer (CF-MIMS) operated from a mobile field laboratory.

The results indicate that agricultural headwater streams are systematically supersaturated in both CO_2 and N_2O, with concentrations primarily driven by groundwater inputs. Degassing of both gases occurs predominantly within the first few hundred meters of the stream network as a result of rapid gas exchange, indicating that measurements conducted further downstream are likely to underestimate riverine GHG fluxes. By integrating high-resolution field data with regional upscaling and a first-order global extrapolation, we estimate that headwater streams represent a substantial share of lotic N_2O emissions. Overall, these results identify upstream sections of stream networks as previously underappreciated hotspots of GHG emissions.