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Application of dual isotope analysis of nitrate to trace the sources of nitrogen compounds in the Lomellina rice-paddy area

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Abstract. The management of nitrogen-based fertilizers in irrigated rice systems is a key agronomic challenge, particularly in Mediterranean paddy environments such as the Lomellina area (Northern Italy), within the main rice-producing district in Italy. In this context, nitrogen inputs may interact with soil redox dynamics and irrigation practices, potentially affecting groundwater quality. Despite this, few studies have investigated nitrate sources and transformations in Mediterranean paddy environments.

This study systematically applies dual $\delta^{15}N$-$\delta^{18}O$ isotope analysis of nitrate in the phreatic aquifer underlying the Lomellina rice district, where groundwater depth ranges from less than 1 m to about 15 m. The objective is to trace the origin and fate of nitrogen-bearing compounds within this rice agroecosystem.

Between June 2024 and December 2025, thirteen monitoring campaigns were carried out at 25 monitoring points tapping the phreatic aquifer. Isotopic data (interpreted through a locally adapted Kendall Plot) were integrated with nitrate concentrations, land use information and records of fertilizers applied at field scale.

Results show that the highest nitrate concentrations (up to 164.49 mg/L) are mainly associated with NH_4^+-based inorganic fertilizers ($\delta^{15}N$ between -5 and +15‰; $\delta^{18}O$ between 0 and +5‰), whereas concentrations between 5 and 15 mg/L can be interpreted as mixed contributions from fertilizer inputs, soil organic nitrogen and atmospheric deposition. In some cases, anomalous isotopic signatures hinder a clear source attribution.

The findings of the study provide a scientific basis for improving fertilizer management and groundwater protection strategies in the Lomellina rice-growing district and in comparable Mediterranean paddy contexts.

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