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Integrating geomicrobology and biogeochemistry to decipher microbial drivers of pesticide cycling in agricultural systems

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Microorganisms play a central role in the transformation and cycling of pesticides in agricultural ecosystems, but their functional roles and coupling with biogeochemical processes remain poorly constrained [1]. This study focuses on Atrazine and S-metolachlor, two herbicides with contrasting regulatory histories: Atrazine was banned in the EU over 20 years ago, whereas S-metolachlor was withdrawn in 2024. Despite these regulatory measures, both compounds and their transformation products persist in soils and groundwater, raising concerns for long-term water quality.

Three agricultural sites in southwestern France, historically contaminated with pesticides and nitrate, were monitored throughout 2024. Soil and groundwater were sampled in relation to hydrological dynamics and fertilization events. 16S and ITS rRNA sequencing (MiSeq) revealed significant temporal and spatial shifts in microbial diversity and predicted metabolic functions (PICRUSt2). Those variations were partly driven by land use, including pesticide, nitrate and organic matter amendments, as well as more global management practices (conventional versus organic).

One historically contaminated site was selected for enrichment cultures. Microbial isolates were obtained from minimal and carbon-rich media supplemented with target pesticides (400 to 1000 mg/L), yielding both bacterial and fungal strains. Degradation assays demonstrated 20 to 60% S-metolachlor and 4 to 15 % Atrazine removal within 21 days, with transformation products detected at concentrations 10 to 100 times lower than the parent compound.

To assess environmental controls on pesticide degradation, soil slurry microcosms experiments were conducted under near *in situ* conditions. Nitrate, organic matter and a reconstructed consortium of native isolated degraders were added separately or in combination. S-metolachlor degradation, microbial diversity and predicted metabolic functions were tracked for 200 days, alongside C, N and S cycling dynamics. While nitrate addition had no significant effect, organic matter addition significantly enhanced degradation rates, highlighting the importance of carbon availability in regulating pesticide transformation.

By integrating field monitoring, laboratory experiments and functional inference, this work provides a better understanding of microbial-mediated pesticide cycling and its coupling with biogeochemical processes. Identifying novel degraders and determining factors influencing degradation helps connect microbial processes to ecosystem-scale dynamics.

[1] Fenner, Canonica, Wackett & Elsner (2013), *Science* 341, 752-758