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Control of transport processes on microbial dynamics and pesticide degradation from μm to mm scales

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Soil microorganisms play a major ecosystem function by degrading agricultural pollutants such as pesticides, thus mitigating their dispersion in the environment and damping their consequences on Earth's biochemical cycles. Understanding the mechanisms at the microbial scale is key to understand the control of remediation efficiency among soils and to propose improvements of ecologically-based agricultural practices.
Soils are among the most heterogeneous microbial habitats on Earth, with separation distances between pesticides and pesticide degraders large enough to see this habitat as a "desert" for microorganisms. In such context, besides physicochemical and catabolic limitations, spatiotemporal access of pesticide degraders to their substrate is potentially a strongly limiting factor of biodegradation.
Unlike 2,4-D, a pesticide that can easily diffuse through soil water films, 2,4-D degraders have been shown by Pinheiro et al. [2015] to be immobile at field capacity at fixed saturation. Infiltration can however move the degraders and enhance biodegradation, suggesting potential positive feedbacks between dispersion and biodegradation.

The objective of this presentation is to formalize the control of the spatiotemporal organizations on pesticide concentration and degradation rates. And more generally, is it systematically beneficial for degraders to disperse, given that their substrate diffuses?

We develop two reactive transport models, from μm to mm scales [Babey et al., 2017], to investigate the interplay between initial distributions, transport processes and metabolic degradative processes. We consider space-limited spots of substrate as substrate initial distributions, and homogeneous isotropic diffusion as transport process. The temporal biological response relies on classical biological metabolic processes such as substrate limitation, microbial growth, mortality, and microbial lag phase. Previously calibrated values were used for diffusion and biological parameters [Babey et al., 2017].

Synthetic simulations show that the interaction between microbial exposition to pesticide and microbial uptake capacities leads to contrasted biodegradation efficiencies. We show that degrader dispersion generally enhances their probability of contact with the substrate from the time substrate gradients are reversed, potentially at the expense of their activity in more diluted environments. Counteracting processes may spatially modulate the efficiency of degradation.

Strong biodegradation heterogeneities can emerge from no-linear interactions between transport and biological effects. Therefore degrader dispersion would be favorable only in specific situations. Results give guidelines to design future experiments to validate the control of respective spatiotemporal organizations of pesticide concentration and degraders.

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