ContiComiC

Assessment of the scientific challenges to better understand the role of the soil-water continuum in maintaining functional microbial biodiversity in agroecosystems

Métaprogramme BIOSEFAIR

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The consideration of environmental continua and interface zones in the study and management of ecosystems is gradually gaining attention in both scientific and operational circles. In this context, the role of the soil-aquatic continuum in maintaining biodiversity and ecosystem functionality (ecosystem functions and services) is often questioned but remains largely understudied. This situation can be explained in particular by the compartmentalization of research by habitat type (terrestrial and aquatic ecologists very rarely work together) and by the conceptual and methodological limitations (particularly in terms of experimental setups that would integrate terrestrial and aquatic compartments) that must be addressed.

Agroecosystems, which involve significant socioeconomic challenges, are ecosystems that clearly illustrate the importance of the soil-aquatic continuum due to the close links

between watersheds and adjacent aquatic environments, particularly in watershed headwaters. While these links have been relatively well studied in terms of the transfer of chemical substances (nitrates, phosphates, pesticide residues, and pharmaceutical residues, etc.), they remain largely overlooked from the perspective of biological exchanges between these environments.

Given their ubiquity and their great taxonomic and functional diversity (which gives them an important role in many ecosystem services), microbial communities serve as model systems that appear particularly well-suited for addressing this type of issue, drawing in particular on the emerging concept of “coalescence,” applied here to terrestrial and aquatic microbial communities that coexist in headwaters.

However, developing innovative and integrated research to study biological exchanges between terrestrial and aquatic environments at soil-water-sediment interfaces requires the mobilization of multiple and complementary areas of expertise, involving research communities that are not accustomed to collaborating with one another.

In this context, the ContiComiC consortium project aimed to bring together, over a two-day period, microbial ecologists and ecotoxicologists working in either terrestrial or aquatic environments to engage in a collective discussion regarding:

- the concepts of “coalescence” and “functional continuum” in agroecosystems, and

- the approaches and methods to be developed to explore these concepts through the study of microbial biodiversity and certain ecosystem services it supports.

Results

A workshop held on November 24 and 25, 2021, brought together 8 participants representing 4 INRAE research units (RiverLy, Agréocologie, CARRTEL, EMMAH) and one non-INRAE research unit (LECA). The workshop was divided into 4 working sessions, which respectively enabled participants to:

- Define the scientific framework and contextualize the concept of microbial coalescence within the soil-aquatic continuum;

- Identify the main scientific challenges surrounding this concept;

- Provide an overview of the existing literature on the subject and conduct a critical analysis of it;

- Define the main conceptual and methodological needs and list the expertise and disciplines to be mobilized.

The discussions as a whole first highlighted the importance of taking into account the various interface zones between environmental compartments (e.g., surface water–sediment; soil–surface water; soil–groundwater, etc.) and the transfer of water and particulate matter (soil and suspended solids), while considering their preferential pathways (Fig. 1). This is essential for identifying, both temporally and spatially, potential “hotspots” of microbial coalescence.

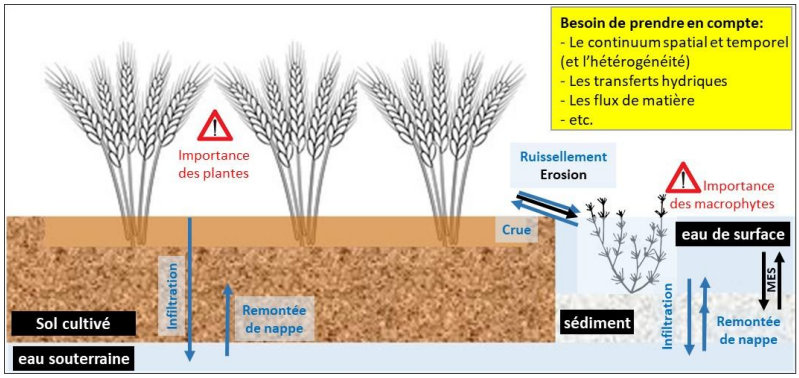

Figure 1: Schematic representation of interface zones and water and material transfer processes in the riparian zone of an agrosystem.

In agroecosystems, microbial communities are present in all environmental compartments (e.g., 1 gram of soil or sediment contains several billion microorganisms representing tens of thousands of species), where they carry out numerous ecological processes that contribute to a wide range of ecosystem functions and services. Among these ecological functions, the following are worth noting (this list is not exhaustive): primary production (phototrophic microorganisms), the decomposition of organic matter and the recycling of nutrients, the biodegradation of organic contaminants (such as pesticides or pharmaceutical substances), the mitigation of soil and sediment erosion, and contributions to gas exchange with the atmosphere. One of the main challenges highlighted by the consortium concerns the need to better understand how coalescence processes at interface zones influence the ability of newly formed microbial communities to fulfill their ecological roles, based on the functions to which they contribute.

The literature review conducted in conjunction with the seminar shows that the vast majority of studies on microbial coalescence processes in aquatic environments focus on the structure and diversity of communities developing downstream of wastewater discharges, sometimes with a focus on antibiotic-resistant populations and, more rarely, on pathogenic microorganisms. The number of studies examining these processes along the soil-aquatic continuum is very limited, and their scarcity is even more pronounced in the context of agrosystems. Furthermore, all of the studies identified have methodological limitations that make it difficult to assess the influence of this continuum on the structural and, above all, functional characteristics of microbial communities. Generally speaking, these limitations concern (i) the spatial and temporal sampling strategy and the lack of details regarding the choices made in this regard, and (ii) the almost exclusive focus on microbial taxonomic diversity without consideration of the functional dimension.

However, it is worth noting that recent methodological developments, particularly in the field of “omics” (from metagenomics to metabolomics) as well as in bioinformatics and biostatistics, make it possible to consider implementing new approaches that are particularly well-suited to studying microbial coalescence processes at various environmental interfaces within agrosystems, addressing this from taxonomic, structural, and functional perspectives. To truly link microbial responses to ecosystem functioning, however, it appears necessary to develop innovative approaches capable of measuring the functional consequences at this ecosystem scale (e.g., in terms of C and N fluxes; the fate of contaminants, etc.).

In conclusion, the discussions and collective reflections confirmed the value of considering the functional soil-aquatic continuum in agroecosystems and the processes of microbial coalescence in the various interface zones found within them. They also clearly highlight the need to draw on a broad range of interdisciplinary expertise to truly understand the role of the

soil-aquatic continuum in maintaining functional microbial biodiversity in agroecosystems. The disciplines to be mobilized (in addition to microbial ecology) include, but are not limited to, hydrology, pedology, (flux) modeling, bioinformatics, biostatistics, and functional ecology.

Scientific perspectives

The involvement of partners specializing in the study of various environmental compartments (soil, water, sediment) has strengthened the shared desire to establish collaborations focused on the interfaces between these compartments. However, these collaborations must not be limited to issues specific to microbial ecology and must include partners from the various disciplines mentioned above. This therefore requires the development of a large-scale project such as an ANR or PEPR initiative (e.g., the “wall-free labs” projects under the PEPR OneWater program), or even an MSCA Doctoral Network at the international level.

As it stands, the consortium is not sufficiently multidisciplinary to develop this type of project, and it might be worthwhile to organize a new forward-looking seminar, opening it up to representatives from other disciplines in order to collaboratively develop the outlines of a joint project.

Knowledge Transfer

The collective discussions held during the ContiComiC seminar contributed to the development of two thesis projects:

- “Impact of PhACs and microbial coalescence on sediment microbial communities and the occurrence of bacterial pathogens disseminating antimicrobial resistance” and

- “Dissemination routes of antimicrobial resistance and pathogens among terrestrial and freshwater ecosystems in agri-urban catchments.”

These topics are funded as part of the European Pharm-ERA project (https://pharm-era.hub.inrae.fr/; MSCA-Doctoral Network), coordinated by Stéphane Pesce, which began on February 1, 2024.