MODIMIV

Modelling the relationship between microbial and plant diversity in multi-species agroecosystems

Métaprogramme BIOSEFAIR

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The MODIMIV project aims to model the relationships between microbial and plant diversity in multi-species agroecosystems, particularly grasslands, in order to improve the simulation of carbon (C) and nitrogen (N) flows and better synchronise nutrient supply and demand. The initial objective was to overcome the limitations of existing models, which often incorporate biodiversity in an implicit or simplified manner, by developing explicit and dynamic simulators capable of representing biotic interactions.

The central hypotheses are that interactions between plant diversity (e.g. grasses and legumes) and soil microbial diversity play a key role in regulating biogeochemical cycles. Grasslands, which cover about 40% of the Earth's surface, can act as carbon sinks or sources. Processes such as biological nitrogen fixation via legume-rhizobium symbiosis or root dynamics influencing organic matter decomposition contribute to better nutrient synchronisation, reducing losses and improving productivity.

The methodological approach is based on combining existing models: ModVege for plant growth, CoSMo for plant species dynamics, and SYMPHONY for soil microbiology. Several M2-level internships have enabled the development of specific modules:

- integration of nitrogen fixation by legumes, based on functional traits such as specific leaf area and leaf lifespan,

- addition of a root compartment to simulate exudate flows and root mortality, with adjustments to the C/N ratio

- analysis of the distribution of functional traits at different spatial scales using the DRY database.

The work is based on numerical simulations, literature reviews and data from field experiments, in particular UREP devices on innovative plant covers such as agroprairies.

The main results include a prototype integrated model of root dynamics, enabling the simulation of new flows, such as the growth gain attributable to biological nitrogen fixation. Functional trait analysis highlights intraspecific variability influencing functional diversity at scales ranging from square metres to ecoregions, with covariations structured by aridity gradients.

Finally, a position paper (Rodríguez et al., under review) compiles more than 300 references and a glossary of 40 terms. It proposes a roadmap for integrating microbial and plant biodiversity into biogeochemical models.

Detaied Results

The major results of the MODIMIV project include the development of an integrated model capable of jointly simulating C and N fluxes, as well as plant and microbial biodiversity. A module dedicated to legumes has been introduced, allowing the simulation of biological nitrogen fixation as a function of environmental factors. In addition, the analysis of functional traits (e.g. height, SLA) from the DRY database has made it possible to quantify diversity at several spatial scales, revealing covariations structured by aridity and a significant influence of intraspecific variability on functional diversity indices. The positioning article proposes a roadmap for modelling interactions between biodiversity and ecosystem services.

Among the difficulties encountered, the complexity of the coupling highlighted a bottleneck related to C-N balances, requiring several iterations, as well as high data variability.

The project also benefited from partnership opportunities, notably with AGROECOseqC for access to data on agro-grasslands, as well as international presentations (e.g. EJP Soil Science Days 2024, Vilnius, Lithuania), enhancing its visibility.

The benefits include practical implications for sustainable grassland management, such as promoting grass-legume mixtures to optimise C storage. Achievements also include open-source code for the modules developed and simulations evaluated from experimental data.

Summary table of progress

Objective	Major results	Practical implication
Couplage of modeles	ModVege-SYMPHONY with root compartment	Better nutrient synchronisation, reduction in nitrogen losses
Legume module	Integrated biological fixation, clover parameterisation	Approximately 30% increase in biomass thanks to biological fixation
Trait analysis	Multi-scale distribution of functional traits	Identification of adaptive strategies to aridity to strengthen resilience
Position paper	>300 references, 7 figures	Roadmap for integrated modelling of biodiversity and biogeochemical cycles

Scientific perspectives

Following MODIMIV, we wish to further explore the explicit integration of microbial diversity into biogeochemical models, particularly through the representation of bacterial and fungal functional groups, as well as the consideration of the spatio-temporal variability of interactions, especially under climatic stress. Louise Adam's PhD, 50% funded by BIOSEFAIR and supplemented by VetAgro Sup for the period October 2024-September 2027, under the supervision of Gianni Bellocchi, is part of this dynamic and opens up new research perspectives.

This PhD addresses several emerging questions: how does microbial and plant diversity contribute to the multifunctionality of ecosystems, particularly for functions related to the C and N cycles (nutrient supply, biomass production, carbon storage, nutrient retention)? What are the controlling factors – soil climate, functional diversity, disturbances – that determine the functioning of synchronous soil-plant systems? How do organisations adapted to local constraints emerge from direct and indirect interactions between plant and microbial communities? To what extent does diversification improve multifunctionality, depending on the compatibility of functional traits with local conditions? And how do these interactions finely regulate carbon and nitrogen fluxes? These questions are explored through the development of explicit, dynamic models that integrate diversity, built on existing models and supplemented by mathematical analyses and validations based on empirical data from mesocosm experiments. Simulations also make it possible to evaluate agroecological practice scenarios, such as the choice of species or functional combinations, in order to optimise ecosystem services.