Modelling the key role of microorganisms in C and N cycles of a cereal-legume agrosystem

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Context & objective

- Most of the models published over past decades and predicting the soil organic matter transformation in the C and N cycles are based on parameters not always linked to the environment and underestimate the role of microorganisms. They are often over parameterized, which can give multiple solutions for flow calculations between state variables.
- This work proposes a parsimonious but process-based model centered on the functioning of living organisms, in order to calculate flow parameters using data on C and N stocks in decomposers, plant organs, symbiotic microorganisms, and the soil compartments in a Mediterranean wheat-legume agrosystem.

Material and Methods

Modelling approach

- The behavior of a wheat-legume agrosystem over time was modelled as a complex system according to **the System dynamics (SD) approach** (stocks, flows, feedback loops ...).
- The model's computer design was done with a systems dynamics software (Vensim®). The MOMOS decomposition module has also been written in R language, with scripts and functions available on request (https://gitlab-ecosols.cirad.fr/).

Model development and structure

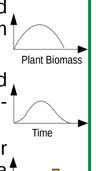
- The whole model contains a Plant and Symbiont module coupled with the core MOMOS module of organic transformations by micro-organisms of the soil..

MOMOS as the core module

Initially proposed from a comparative prediction of ^{14}C flows in tropical fields [1], mathematically linked to climate data, biological properties of plant residues, soil moisture and soil texture [2, 3], the MOMOS model was validated [4], and then extended to prediction of ^{15}N flows in 6 contrasted tropical ecosystems [5]. It was then tested on cereal-legume cropping systems in a non-fertilized Mediterranean soil, to model the C and N flows between plant-organs and micro-organisms through the measurement of few state variables [6,7]. The mathematical validity and stability of the solutions of MOMOS non linear system of differential equations were also demonstrated [8].

Notes on the whole model structure

- MOMOS fluxes depend on kinetic parameters weighted by functions of soil moisture and temperature.estimated by the Soil and Water module.
- Fluxes are source-dependent with constant rates ($F_i = k_i * S_i$) with the following notable exceptions:
  - microbial respiration ($= q_r * MB^2$)
  - plant production (depends on plant biomass (y) with a bell-shaped response curve of the form $F \sim y(1-y/y_{max})$.
  - grain filling, litter production and nodule growth&mortality (Gauss-shaped time-dependent functions).
  - harvest and harvest-associated litter production (time-dependent delta function).



- OM inputs into MOMOS module are reallocated into labile and stable fractions with the TAO module based on fibre fractionation data [9]
- N mineralization/immobilization keeps microbial biomass C:N ratio fixed.

- Soil microbial respiration and symbiotic nodules of the legume produce atmospheric CO_2. Atmospheric N_2 is fixed by the nodules. Soil inorganic N is transferred to plants and soil micro-organisms.

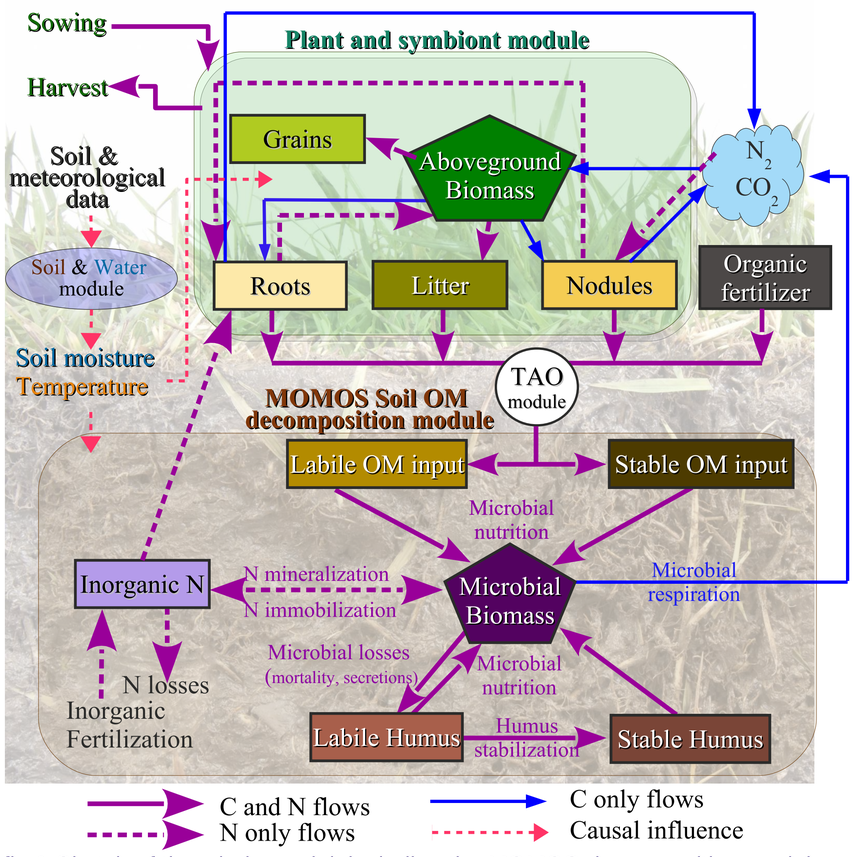


fig.1-Sketch of the whole model, including the MOMOS decomposition module.

Field experiment and data collection

(for full description cf. Ibrahim et al. (2016) [6]).

Field experiment in 2011, located on INRA UE Diascope station, Melgueil, France *(43°37'32"N, 3°59'20"E)*. **Climate is Mediterranean**: 631 mm (4 mm Aug., 268 mm Nov.); T 2.4°C Jan. & 28.5°C Aug. **Soil is loamy chromic Cambisol with decarbonatated brown-reddish upper horizon** *($CaCO_3$ < 2%, pH ~ 8.2)*. **Three cropping systems** without fertilizers were compared : **faba bean** *(Vicia Faba)*/ **durum wheat** *(Triticum durum)*/ **Intercropping faba bean–durum wheat**.

Data collection for model calibration: Daily air temperature and rainfall; Soil surface CO_2 production; Soil 0-30 cm layer texture, bulk density, total and organic C% and N%; microbial C%, N% and biomass; Plants (roots, shoots, grains) and symbiotic N_2 fixing nodules biomasses, C% and N%; fiber fractionation.

fig.2-Few steps in the field and in the labs.

Some results

1. *Quick exchanges of N between microorganisms and other compartments during the growing season*

- During the growing season, microbial N increases, quickly depleting the inorganic N stock (fig.3). The N flows (fig.4) between microorganisms, organic inputs and labile humus suggest rapid N exchanges.

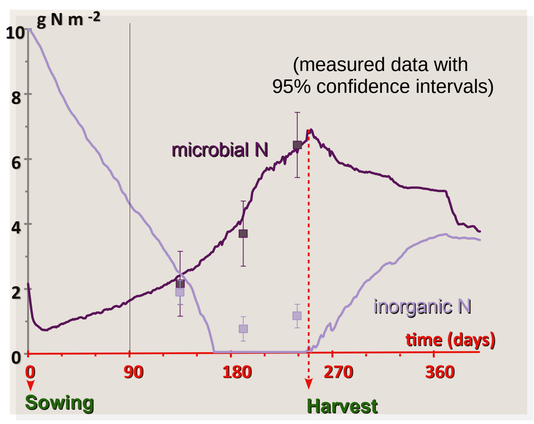


fig.3-Measured and predicted evolution of inorganic N and microbial N (faba bean in intercropping)

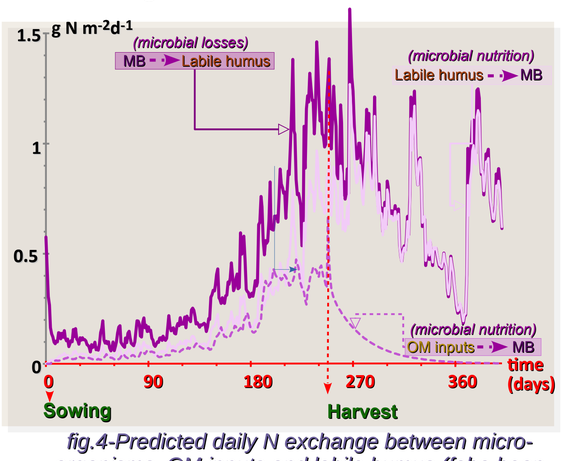


fig.4-Predicted daily N exchange between micro-organisms, OM inputs and labile humus (faba bean in intercropping).

2. *The soil of intercropping system appears as a sink of labile C.*

- During cultivation, the C inputs in the soil from OM plant debris are greater than the C outputs by soil respiration (fig.5). However, only the labile humus increases in the soil (fig.6).

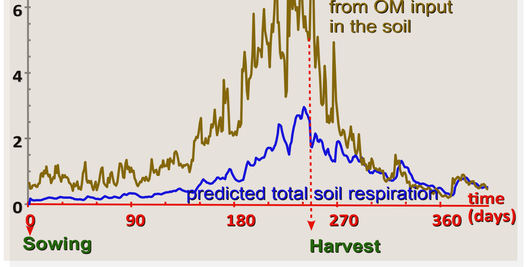


fig.5-Predicted daily balance of C inputs in soil from photosynthesised material and C losses by respiration.

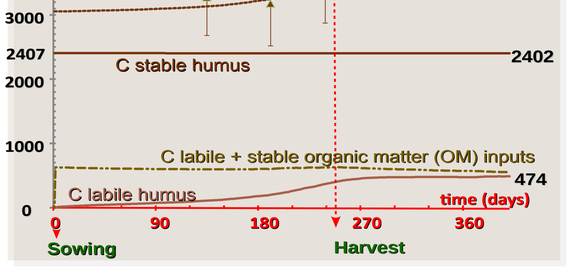


fig.6-Measured and predicted values of soil total C and modelled values of C in OM inputs and in humus.

3. *The efficiency of symbiotic nodules for N_2 fixing and plant growth is improved in intercropped faba bean.*

- The model is able to estimate the atmospheric nitrogen fixation by symbiotic nodules (fig.7). It predicts a better efficiency of these nodules in intercropping (fig.8), in agreement with recent data for the experimental station [10].

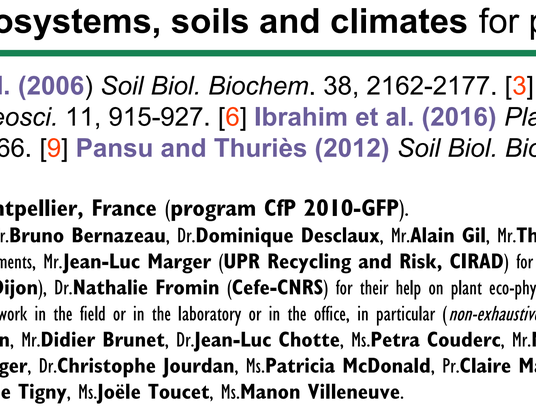


fig.7-Predicted atm. N_2 fixation by symbiotic nodules of faba bean (intercropping system).

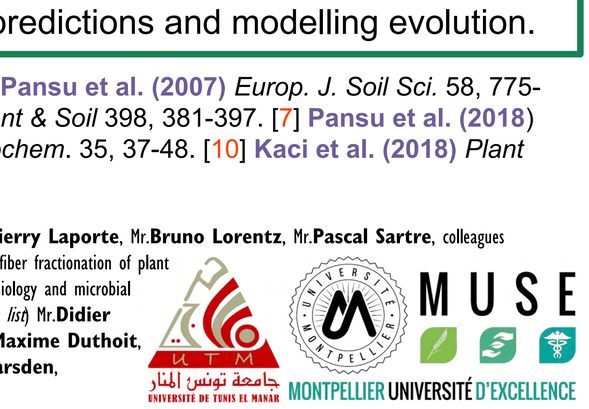
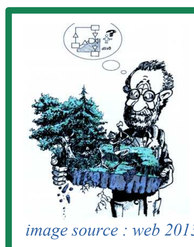


fig.8-Predicted relationships between shoot C and nodule C of faba bean (mono and intercropping).

Conclusion & prospects



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- **Based on the microbial functioning scheme of MOMOS validated in mediterranean conditions, the parsimonious model presented here enables realistic estimations essential in agro-ecology and global change predictions** such as plant growth and nutrition, and sometimes very difficult to measure, such as microbial and root respirations, continuous emission and sequestration of greenhouse gas CO_2, humus storage, N losses and N exchanges between decomposers, plant roots and (for legumes) nitrogen-fixing symbiotic nodules.
- **This model deserves to be tested over longer durations, in various ecosystems, soils and climates** for predictions and modelling evolution.

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