Microorganisms-substrates interactions during the biodegradation of plant litter in agroecosystems

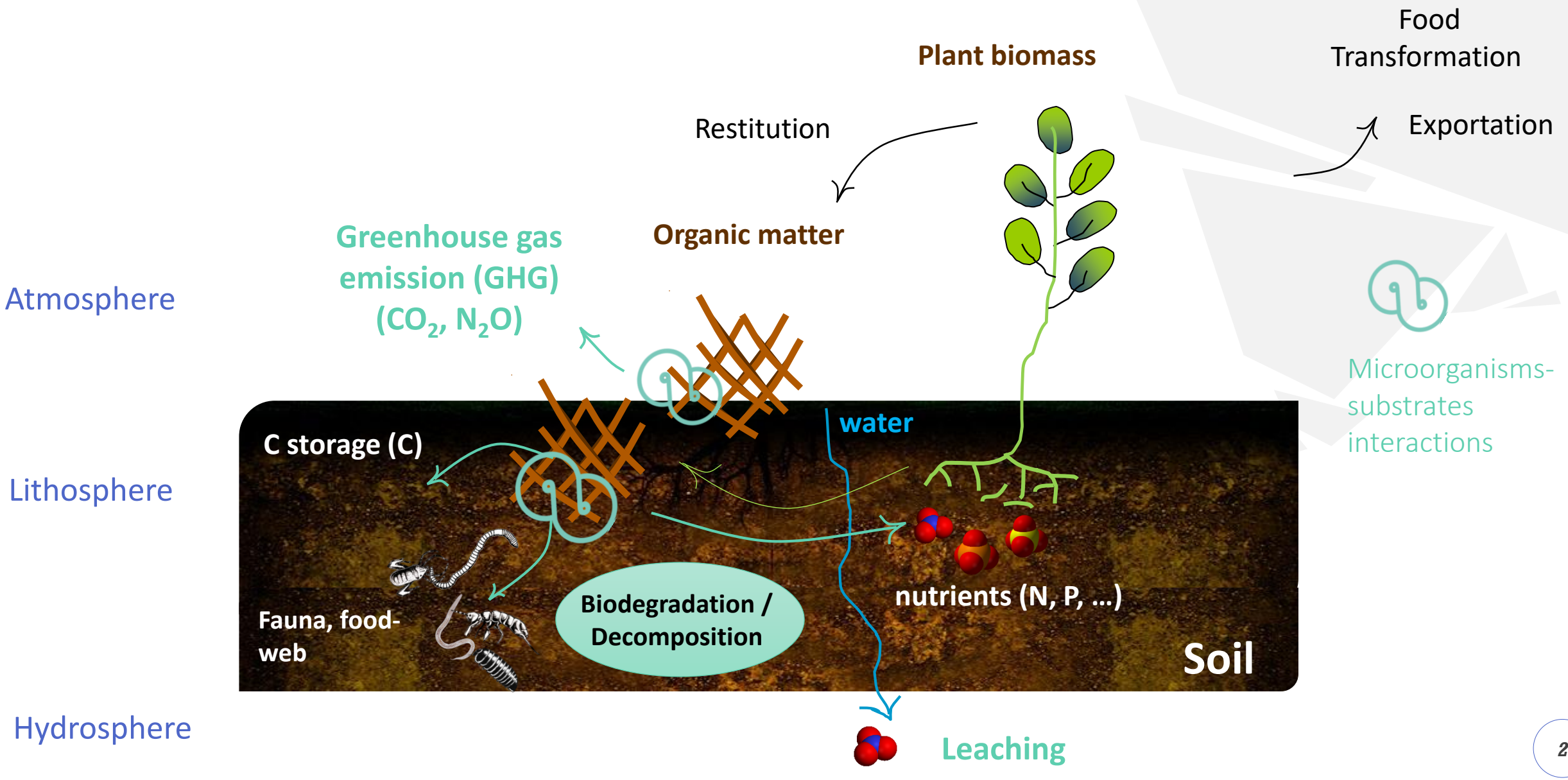
GWENAËLLE LASHERMES gwenaelle.lashermes@inrae.fr

Research Director at INRAE

Fractionation of AgroRessources and Environment (FARE) lab

Scientific Webinars series between LUKE & EXEBIO 5th edition on « Microbial Community »

Plant litter biodegradation in agroecosystems: a central process



Context and challenges for agriculture, food and environment

- Ensuring food security
- Sustainably manage the natural resources essential to life
- Reduce global warming:
  - reduce GHG production
  - increase carbon (C) storage
  - produce energy

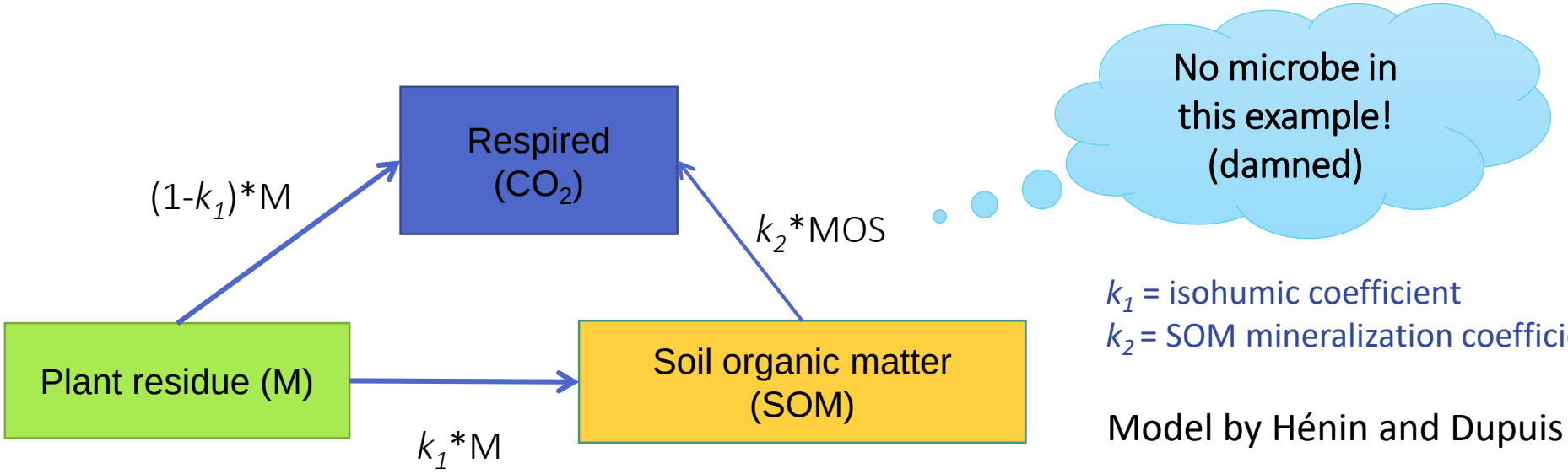
Challenges: Optimize the use of C and nutrients (N, P) from organic resources recycled in soils to preserve soil C sinks and better close biogeochemical cycles

6 of the United Nations' 17 sustainable development goals are linked to these issues

Numerical models: useful tools for understanding & predicting

- Conceptualize our understanding of processes, prioritize factors
- Predict how to recycle N, make GHG assessments, pay/ remunerate beneficial cropping practices

BUT the ecology of microbial communities is usually not represented in predictive models



k_1 = isohumic coefficient
k_2 = SOM mineralization coefficient (yr^{-1})

Model by Hénin and Dupuis (1945)

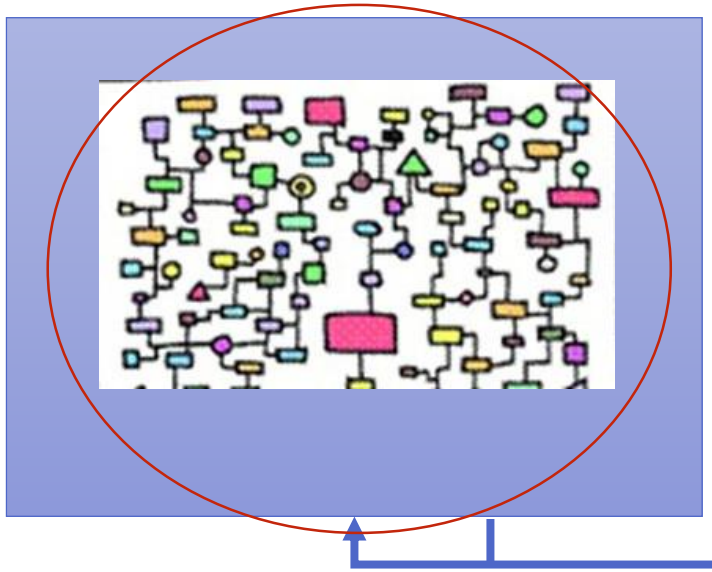
The ultimate goal is building confidence in projections of soil C feedback to climate change

(Bradford et al., *Nat Clim Chang* , 2016)

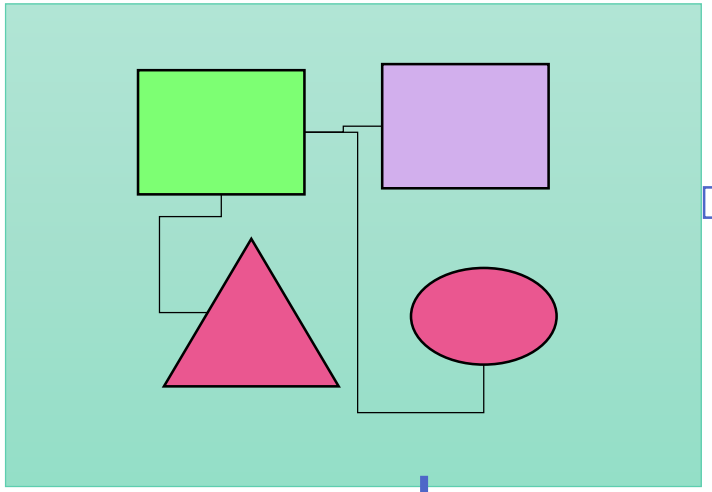
From simulation to prediction

- Different model types
- A progressive, iterative process

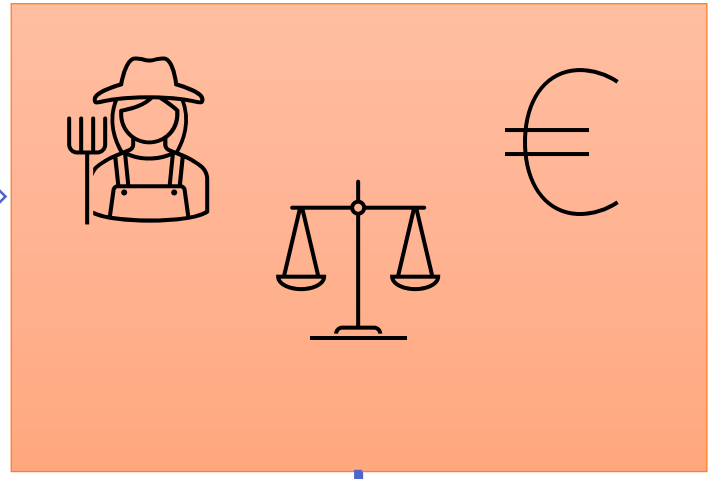
Understanding the mechanisms



Integrating knowledge in a specific context



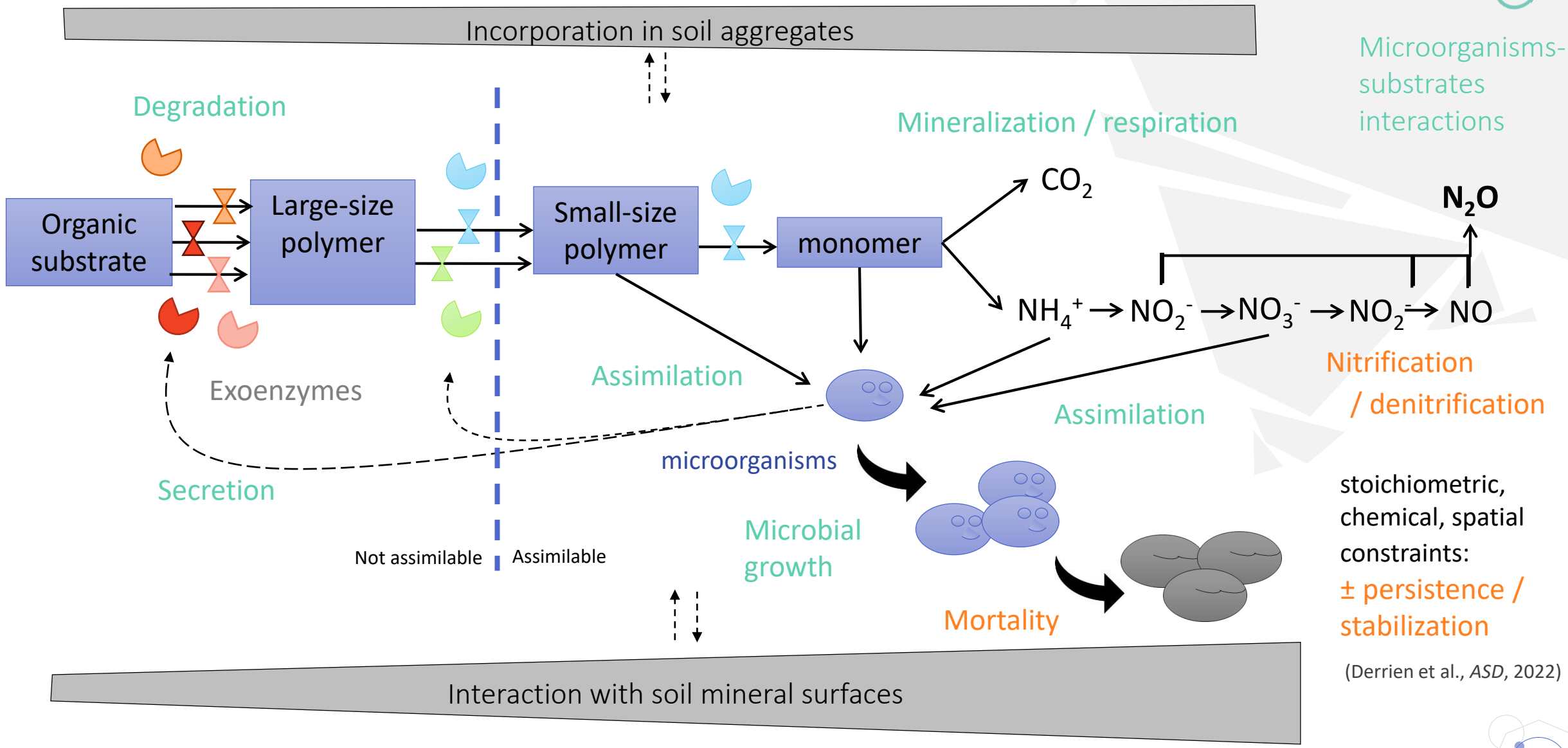
Predict (in this context), incorporate model in decision support tool



My main focus

Revising integration and knowledge when the context changes (climate, practices, discoveries...)

Let's go deeper into plant litter biodegradation in soil



Microorganisms-substrates interactions

stoichiometric, chemical, spatial constraints:
± persistence / stabilization

(Derrien et al., *ASD*, 2022)

(adapted from Lehmann et Kleber, *Nature*, 2015)

Exoenzyme biodegradation

1

What are the investments of microorganisms in enzymatic activities to acquire their resources and the impacts on the microbial C-use efficiency (CUE)?

- Model development (~ theoretical framework) Exoenzymes (EEZY)

↓

- Experimentation with a microorganism as an *in vitro* "experimental model »

↓

- Testing the significance of physiological indicators in the field

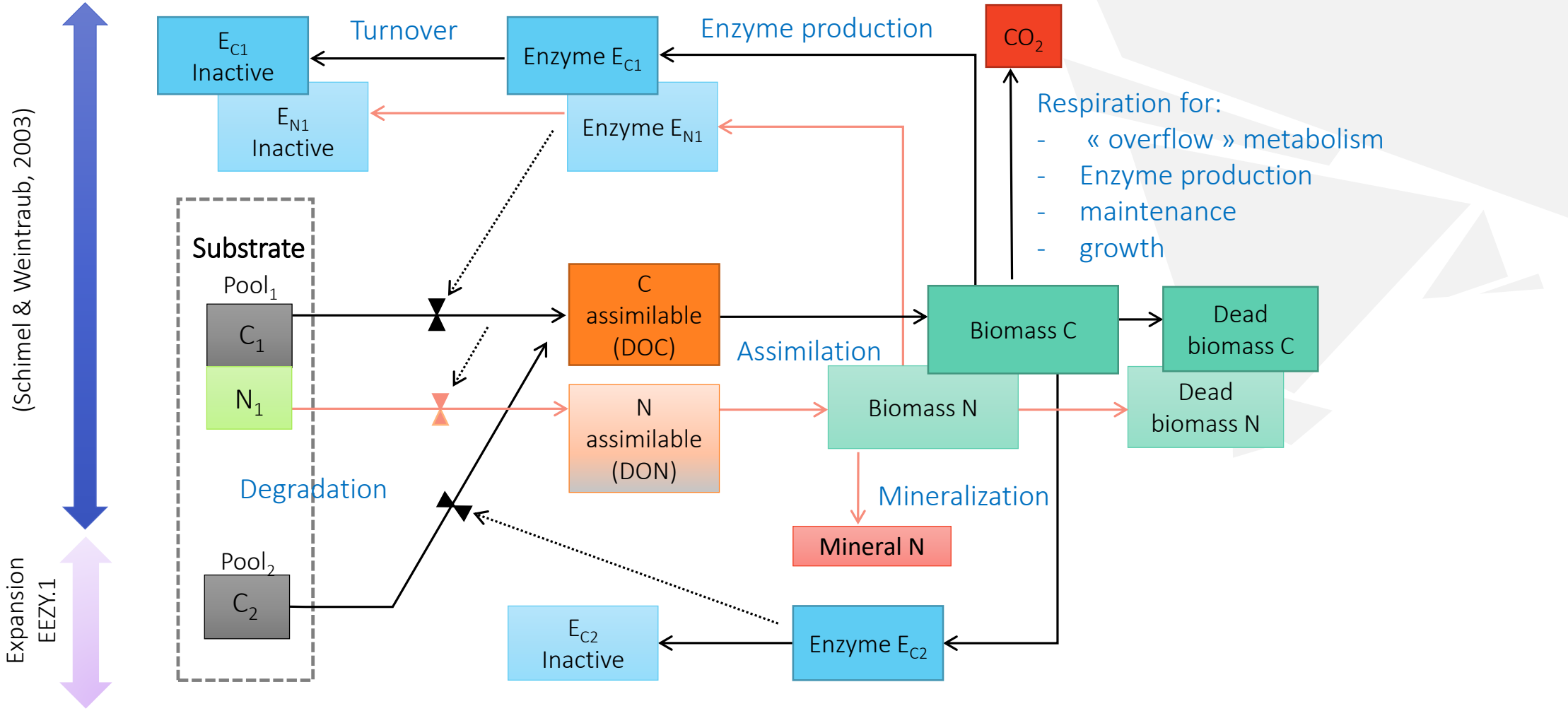
↓

- We extend the concept to a set of terrestrial ecosystems and the N (on going)

ExoEnzyme EEZY.1 model development

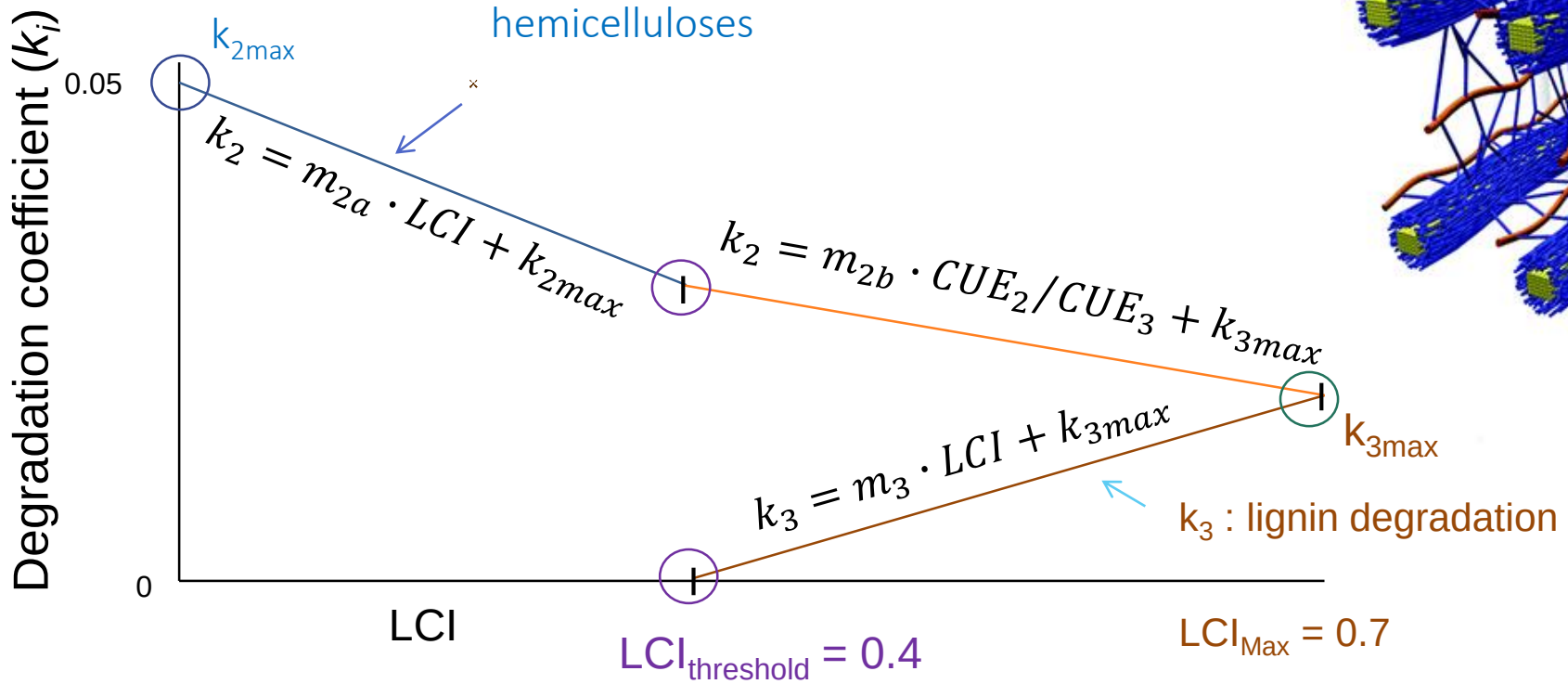
The activities of extracellular hydrolytic C and N

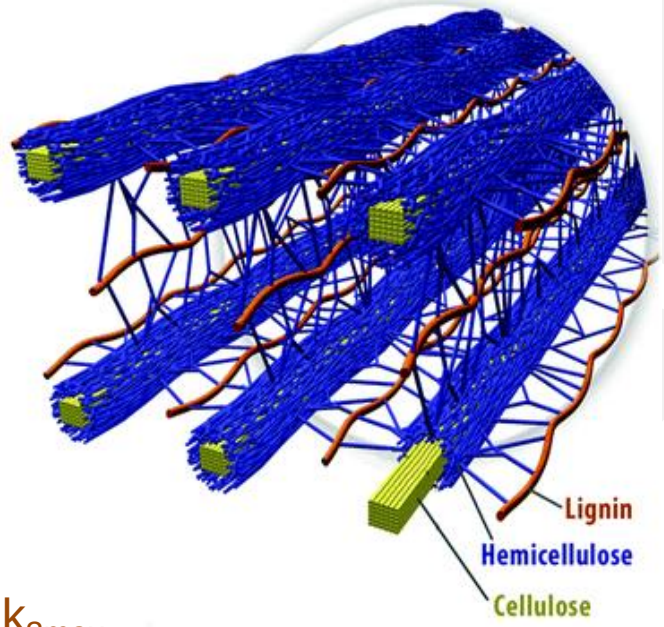
Control of decomposition between energy supply (C) and nutrient supply (N)



(Moorhead, SBB, 2012)

The metabolic cost of lignin degradation

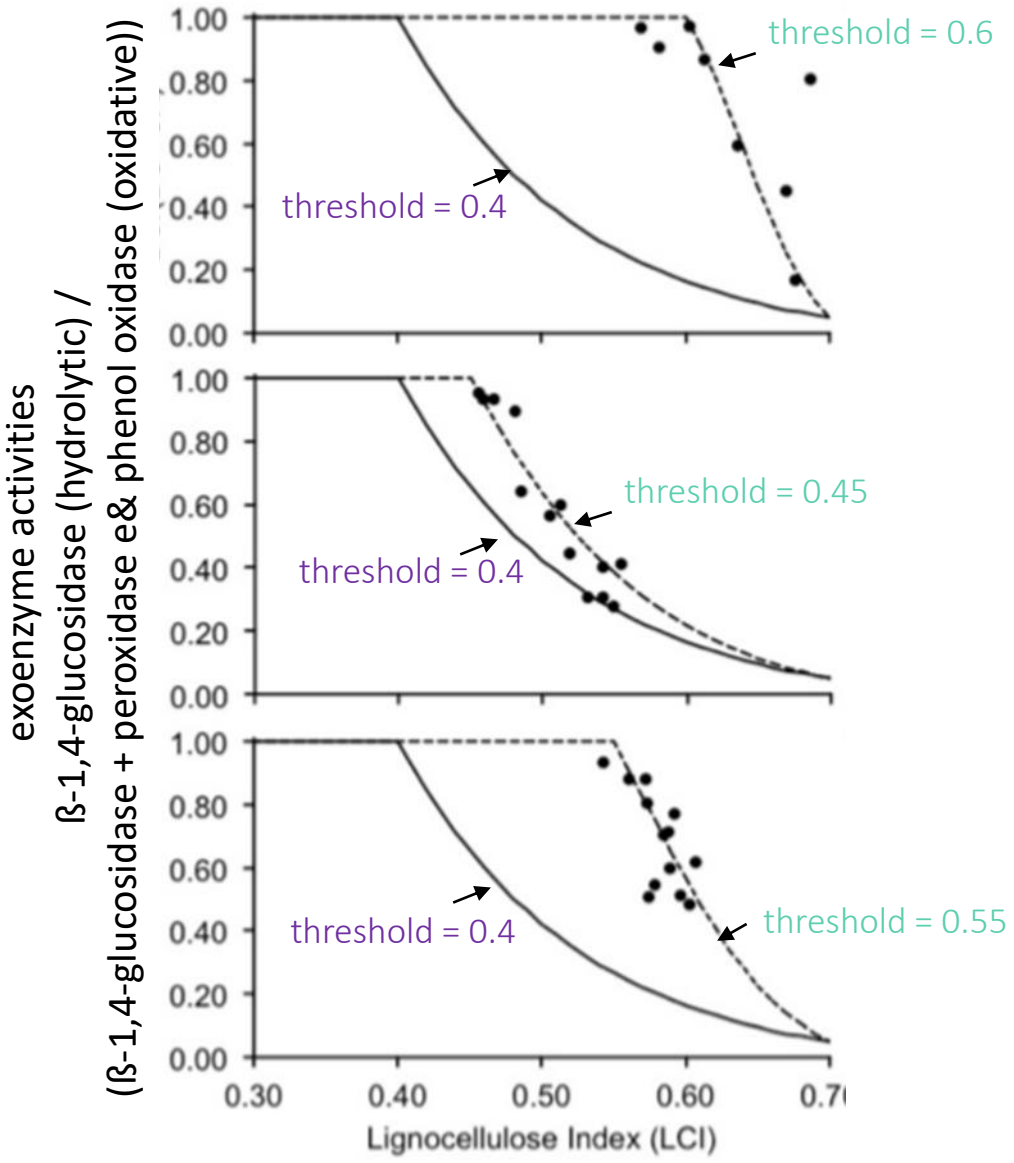




lignocellulose index $$LCI = \frac{lignin}{lignin + hemicellulose + cellulose}$$

(Moorhead, SBB, 2013)

EEZY 2 : control of hydrolytic and oxidative enzyme activities



Oak litter

Prague

(Snajdr et al. 2011)

Oak litter

Harvard

(Magill et Aber, 1998)

Maple litter

New York

(Carreiro et al. 2000)

Optimization of lignocellulosic index threshold values at which oxidative enzymes are produced

Optimized LCI threshold

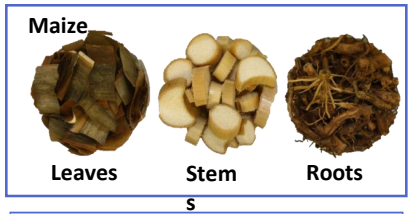
Example of factor: N availability

(Margida, M.G., SBB, 2020)

Biodegradation: "without soil" with a model microorganism

Experiments with the fungus *Phanerochaete chrysosporium*

Incubation
25°C,
5 g DM / microcosm



Sterilized litter ° fungus

14 days

Fungal assimilation (% initial C)

Respiration (% initial C)

Maize leaves

27.3 ± 0.3

13.8 ± 0.6

CUE = 0.63

7.7 ± 0.7

8.2 ± 0.3

CUE = 0.40

Roots

Stems

5.6 ± 0.9

8.8 ± 0.9

CUE = 0.38

Solubles (+)

N (-)

Enzymes are "expensive" in N: no investment in enzymes

arabinose / xylose (+)

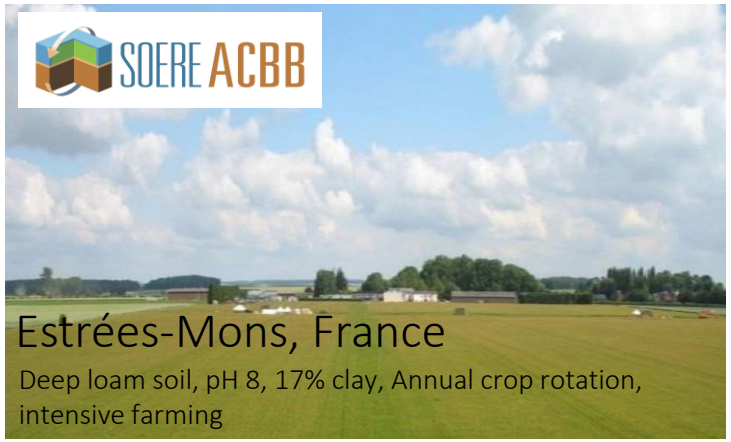
Cell wall compounds (+)

Investment (µmol mg^{-1} C-fungus) in enzymes but they are ineffective (recalcitrance) (µg - decomposed mol^{-1})

(Lashermes et al., *Frontiers in Microbiology 7*, 2016)

Biodegradation: the effect of cultivation practices

Comparing the effects of two field crop practices



Conventional tillage

(28 cm)

Reduced tillage

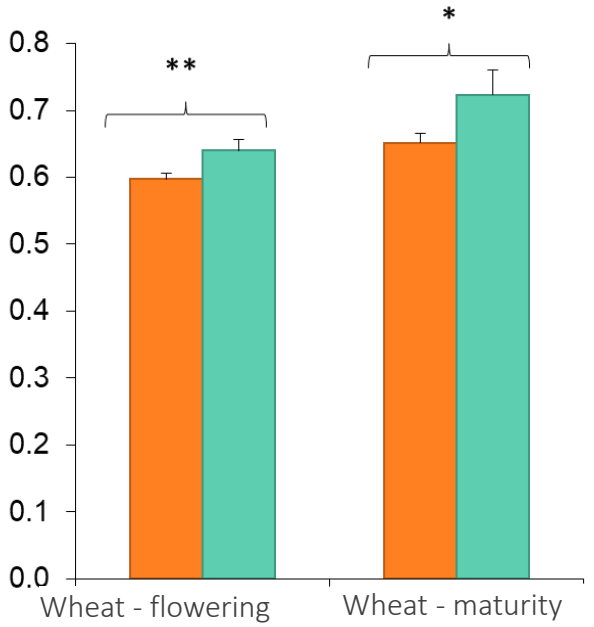
(7 cm)

Firmicutes
Thaumarchaetes
Basidyomycetes
Glomomycetes

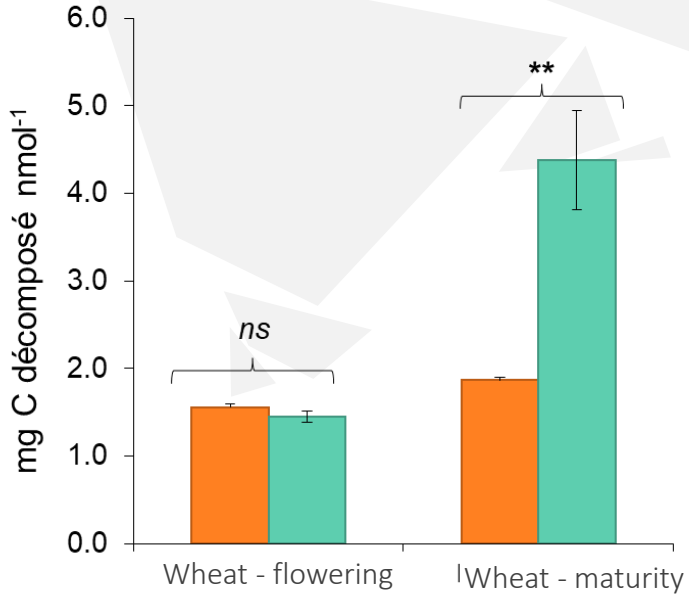
Microbial diversity

Fungi/bacteria : +
Bacteroidetes
Proteobacteria
Ascomycetes

C-use efficiency (CUE)



Enzyme efficiency



\+ ^{13}C-Wheat

surface layer 0-5cm, 4 days

= 2 microbial « legacies »

(Sauvadet, Lashermes et al., *Soil Biology Biochemistry* 123, 64-73, 2018)

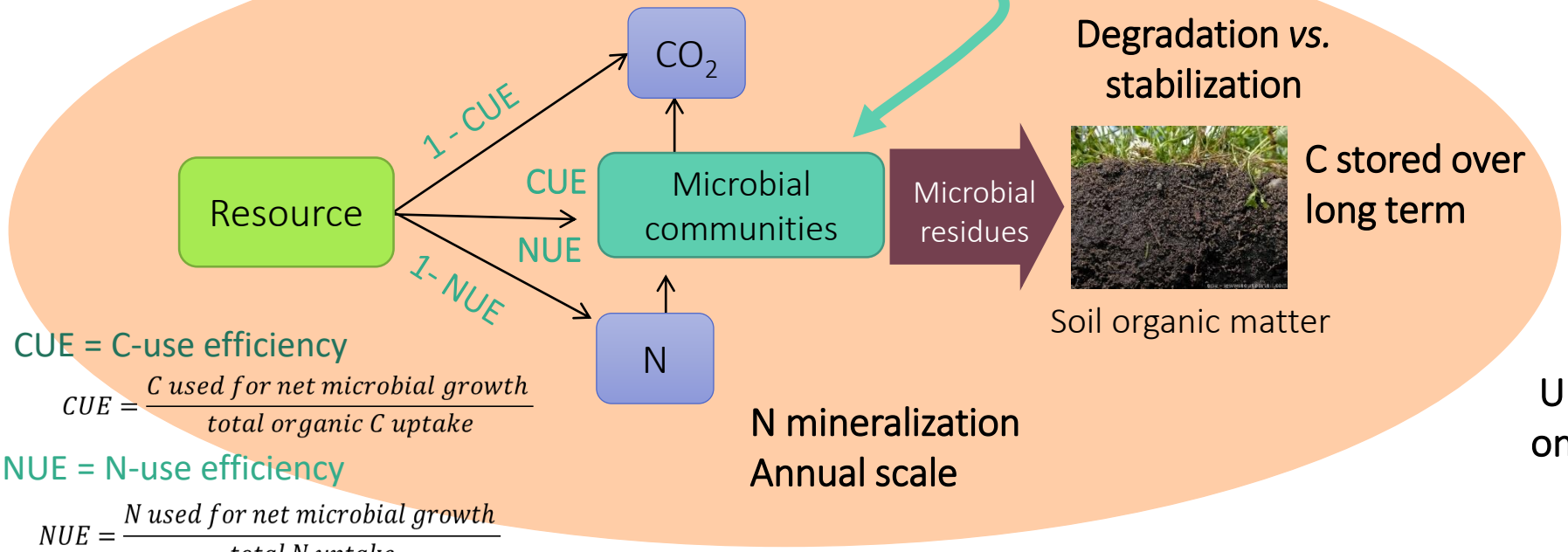
Impacts of microbial functioning on the soil functions of the C&N cycles

- Crop
- Temporary grassland
- Permanent grassland
- Agroforestry
- Forest

Long-term experiments with well-defined practices and environmental conditions to provide **a snapshot of factors and microbial legacy**: comparison of treatments in each site with contrasting management practices

Coordinator
1,5k€, 5 yr
16 French labs

Soil biotic legacy



Degradation *vs.* stabilization

Soil organic matter

C stored over long term

N mineralization
Annual scale

CUE = C-use efficiency

$$CUE = \frac{C\ used\ for\ net\ microbial\ growth}{total\ organic\ C\ uptake}$$

NUE = N-use efficiency

$$NUE = \frac{N\ used\ for\ net\ microbial\ growth}{total\ N\ uptake}$$

Spatial & temporal integration through modeling

Models

Understanding on a small scale

Large-scale prediction

The determinants of plant litter decomposition

2

What are the determinants of decomposition of organic matter in the soil to predict their C and N mineralization, and **their coupling with N_2O emission processes**?

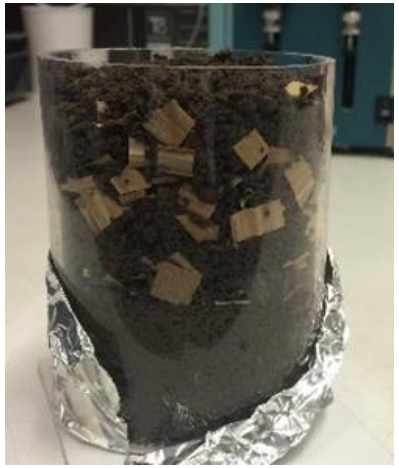
- The role of substrate quality in N_2O emissions during crop residue decomposition

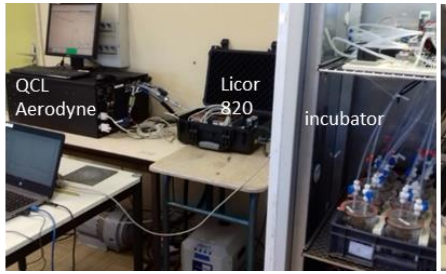
AARHUS UNIVERSITET EcoSys NMBU SLU Swedish University of Agricultural Sciences ADAS KIT Karlsruher Institut für Technologie SRUC NORSØK Norwegian Centre for Organic Agriculture

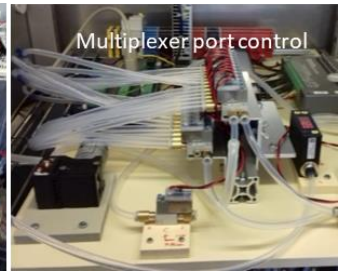
FACCE ERA-GAS MONITORING & MITIGATION OF GREENHOUSE GASES FROM AGRI- AND SILVI-CULTURE RESIDUEGAS

Cofund for Monitoring & Mitigation of Greenhouse gases from Agri- and Silvi-culture.

N_2O emissions association with plant degradation

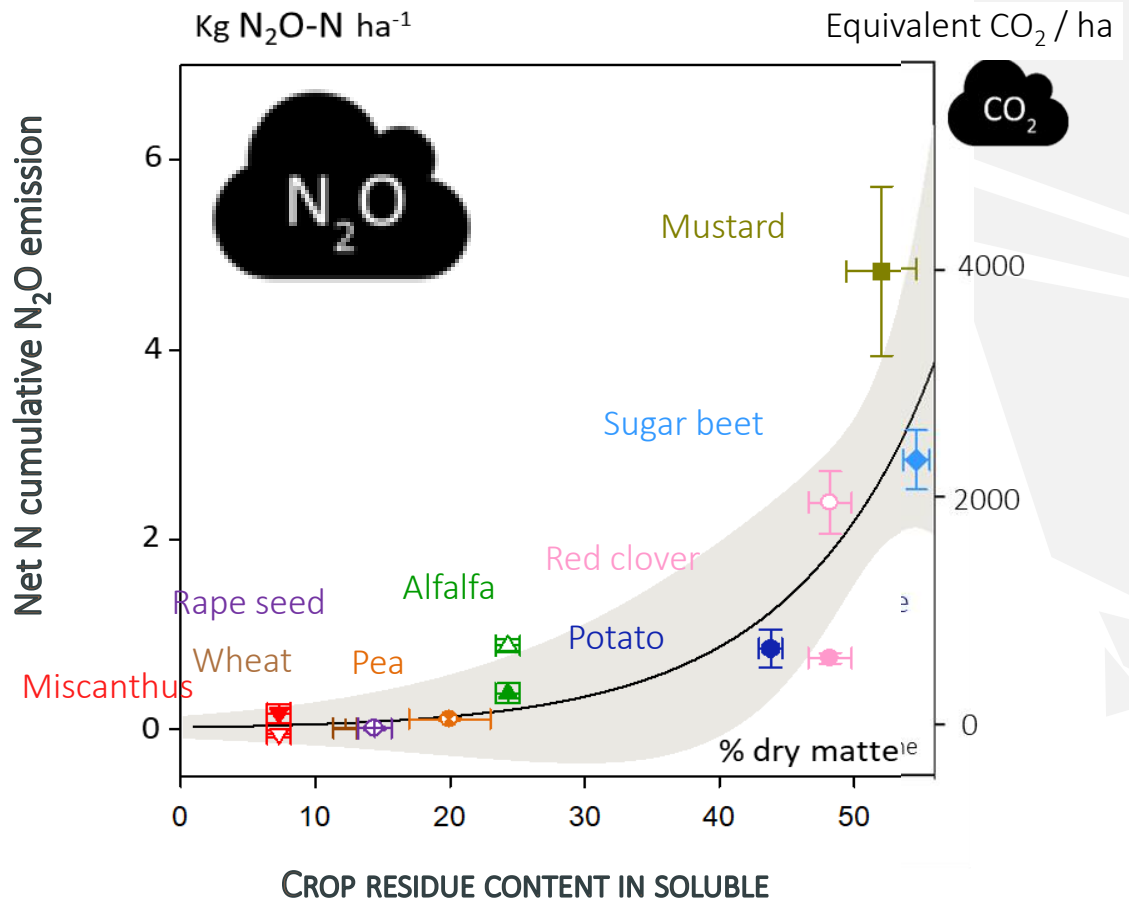






Incubation
4 t DM ha^{-1}
15°C, 60% WFSP
density 1.25, 60 days

(Lashermes et al. *STOTEN*, 2022)




Mustard


Sugar beet


Red clover


miscanthus

High *senescence* — PHYSIOLOGICAL MATURITY OF THE CROP — Low *green stage*

Conclusion : the favorite research objects of my group

Organic substrates

Organic residual products

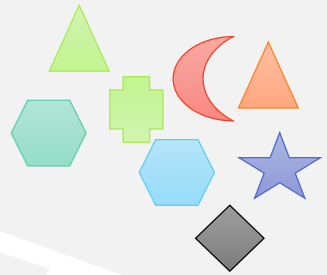
Crop residues

Plant cover

Root litter

Fibber plant

Microbial communities



CUE = C-use efficiency

NUE = N-use efficiency

exoenzymes

Environment

On / in the soil

Abiotic conditions

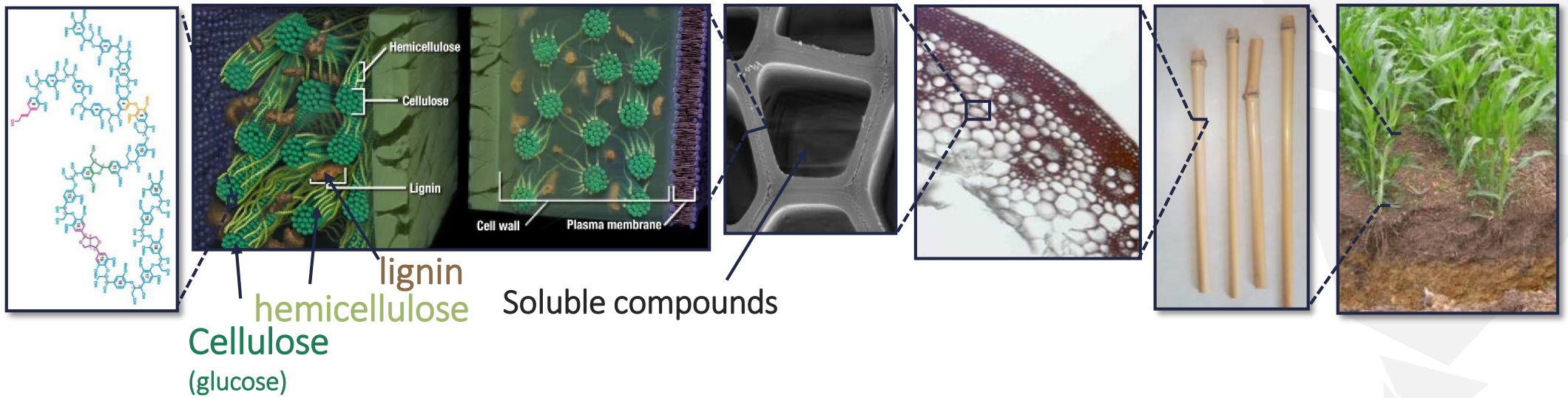
Management practices

Climate

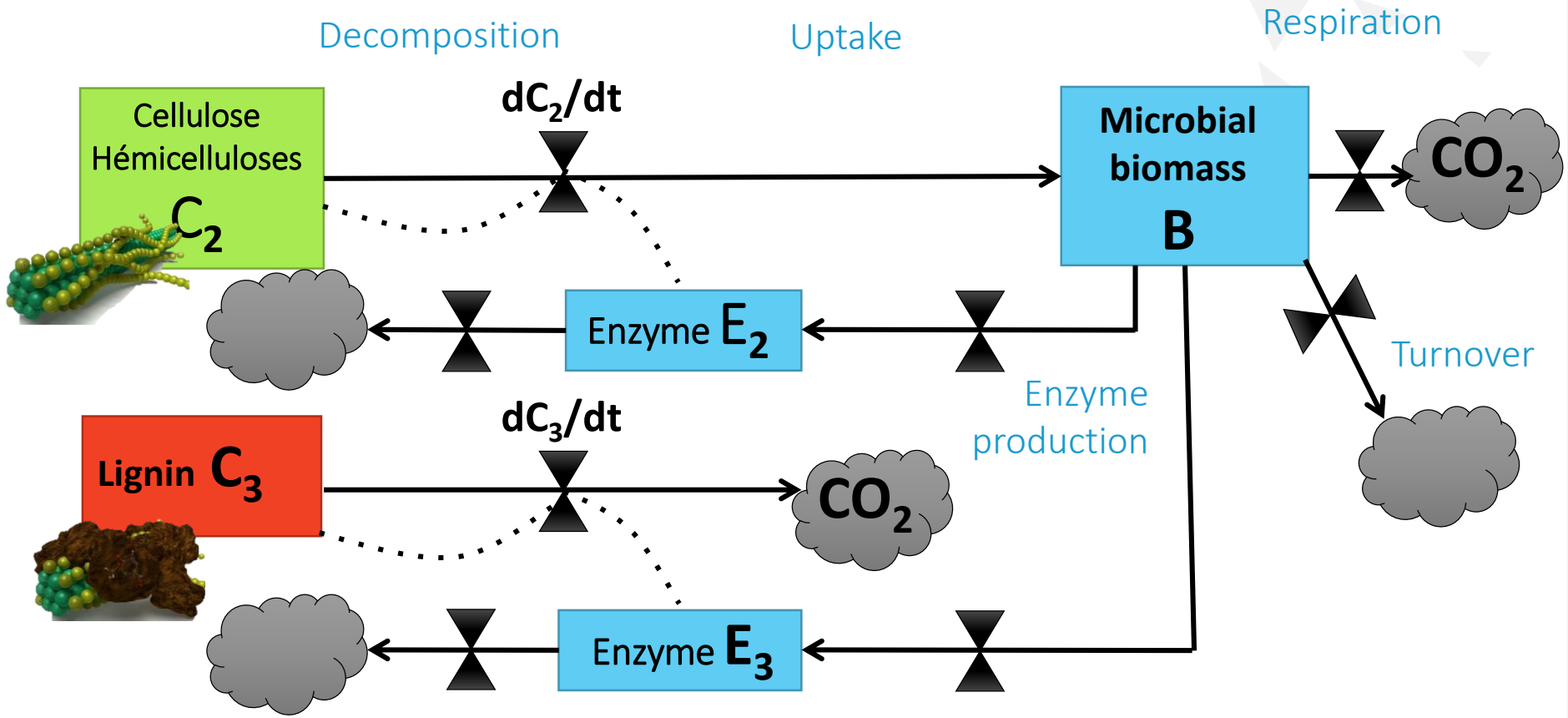
Thank you to your attention!

Many thanks to the scientists, technicians and students from the FARE lab

Different scales of plant litter biodegradation



EEZY-2 model



(Margida, et al., *SBB*, 2020)

Theoretical analytical model and test on long-term litter decomposition data from the literature