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Soil structure -soil microorganisms interactions: decomposing organic matter in a structured world

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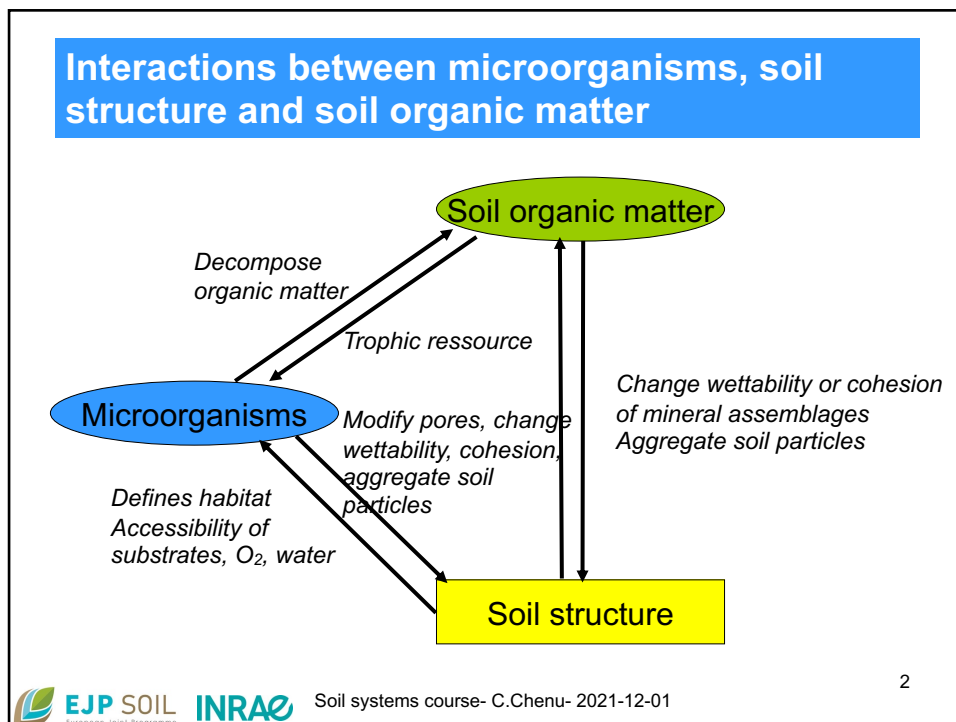
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Soil structure - soil microorganisms interactions: *decomposing organic matter in a structured world*

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1- Does structure matter for biodegradation of organic matter ?

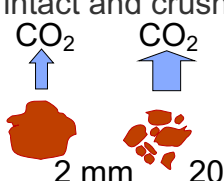
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Soil structure does matter: crushing experiments

- Incubating intact and crushed aggregates



$\Delta\text{CO}_2 = \text{physically protected SOC}$



2 mm 200 µm

Treatment	Scale	C mineralization crushed/intact		
		nb	mean	range
Crushed <1 mm	Macroaggregates	6	1.3	0.8-2.3
Crushed < 0.25 mm	Microaggregates	12	1.17	1.04 -1.3
Crushed < 0.15 mm	Microaggregates	4	1.24	1.14 -1.34
Ground < 0.15 mm	Microaggregates	4	7.1	4.3-10.8

Litterature review (Balesdent et al. 2000)

→ Aggregates protect SOC and protection is more important at finer scales

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Soil structure does matter: manipulative experiments

- N mineralization from soil after plant residues addition:

Breland, 1994, P&S

→ less N mineralization of homogenously distributed residues: protection by the matrix ?

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Soil structure does matter: manipulative experiments

- Manipulating the spatial distribution of μ and substrates

Sterility control Abiotic control Homogeneous distribution Co-localized distribution Separated distribution

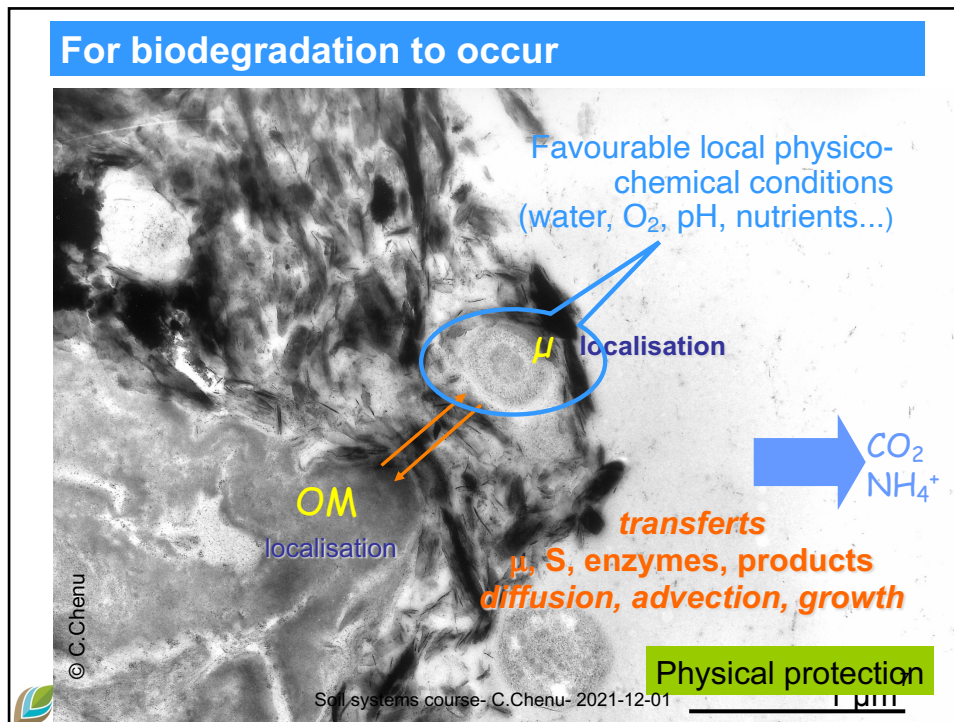
1.9 μg 2,4-D g^{-1} soil 0.015 μg 2,4-D g^{-1} soil

○ Sterilized aggregates
 ● Sterilized aggregates amended with 2,4-D
 ● "Natural" aggregates with soil indigenous microorganisms
 ● "Natural" aggregates with soil indigenous microorganisms and amended

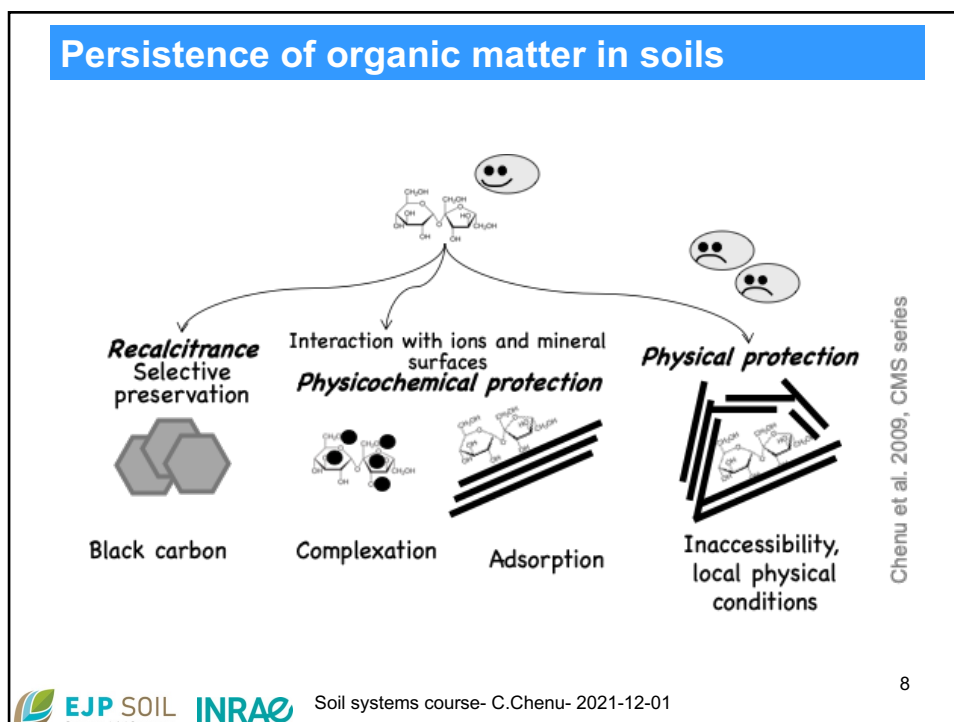
→ accessibility controls mineralisation

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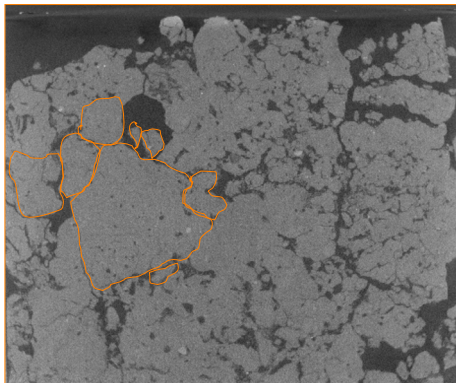
2- Spatial heterogeneity of microbally - mediated biodegradation

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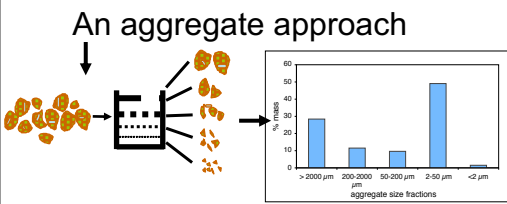
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How is soil structure viewed ?





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An aggregate approach



Aggregate size fractions (µm)	% mass
> 2000 µm	~25
200-2000 µm	~10
50-200 µm	~10
2-50 µm	~55
< 2 µm	~1

Aggregate size distribution

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Separating SOM in different locations & measuring their residence time

- Aggregate of ≠ sizes

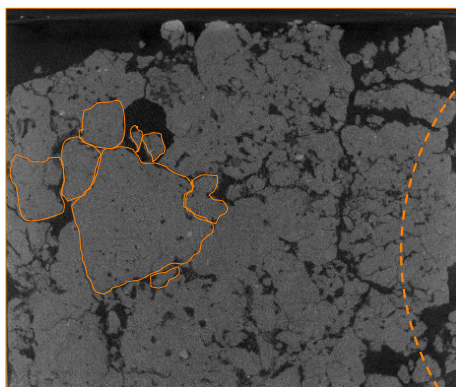
Ecosystem	macroaggregates		microaggregates	
	Size (µm)	MRT (y)	MRT (y)	Size (µm)
Tropical pasture	> 200	60	75	< 200
Temperate pasture	212-9500	140	412	53-212
Soybean	250-2000	1.3	7	100-250
Maize	>250	14	61	50-250
Maize	>250	42	691	50-250
Wheat-fallow, NT	250-2000	27	137	53-250
Wheat-fallow, CT	250-2000	8	79	53-250

Litterature review (Six & Jastrow, 2002)

- Particulate organic matter free vs occluded
 - Higher residence time inside aggregates (Golchin et al. 1995, Besnard et al. 1996, Six et al. 1998, ect...)
 - Turnover of SOC is slower within aggregates and in small ones

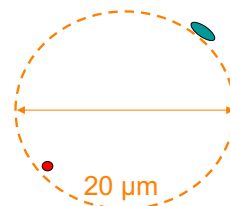
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Protection of OM by soil aggregates: problems



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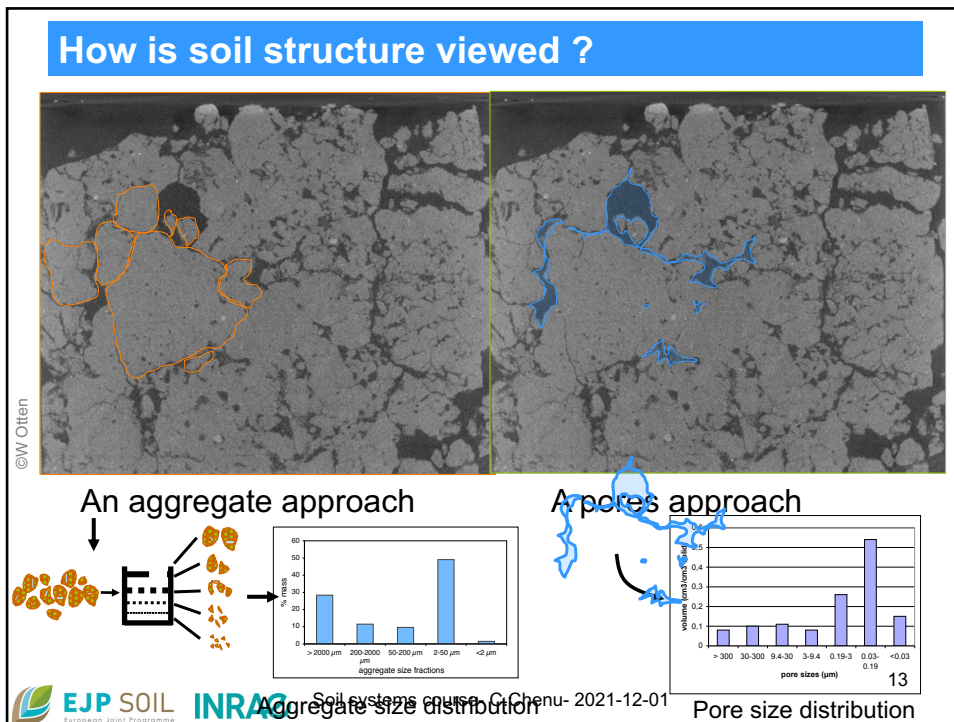
Pb 1: scales !



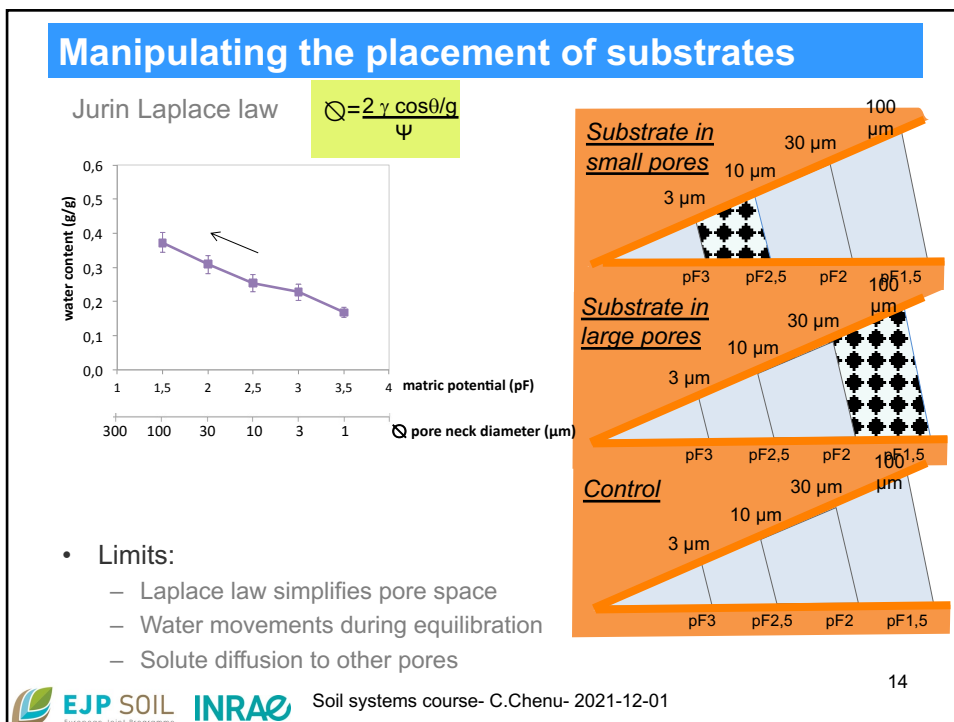
50 µm

Pb 2: turnover rate of aggregates: days ! (Plante et al. 2002; de Gryze 2004) or a year (Virto et al. 2010)

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≠ microbial activities in ≠ pores size classes?

Experiment 1 Native soil microbial community

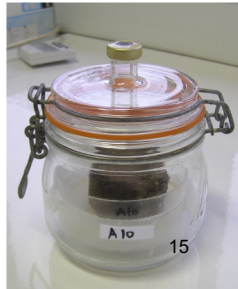
- ¹³C labelled fructose solution or water added at different matric potentials to soil cores

Ψ (kPa)	∅ pores targeted
-1000 → -100	0.3 → 3 μm
-315 → -3,15	1 → 100 μm
-31,5 → -1	10 → 300 μm



$$\varnothing = \frac{2 \gamma \cos\theta}{\Psi}$$

Postulate: consumption of ¹³C labelled substrate primarily in pore size classes targeted

- Incubated for two weeks : total and ¹³C-labelled CO₂
- At end of incubation: total PLFA profiles and ¹³C-enriched PLFA profiles



Ruamps et al. (2011) Soil Biol & Biochem
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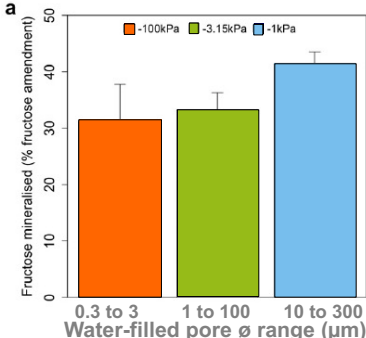



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≠ microbial activities in ≠ pore size classes ?

Experiment 1 Native soil microbial community

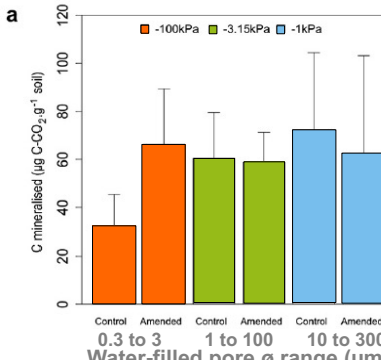
¹³C-fructose mineralisation



Fructose mineralised (% fructose amendment)

Water-filled pore ∅ range (μm)



Native SOM C mineralisation



C mineralised (μg C-CO₂.g⁻¹ soil)

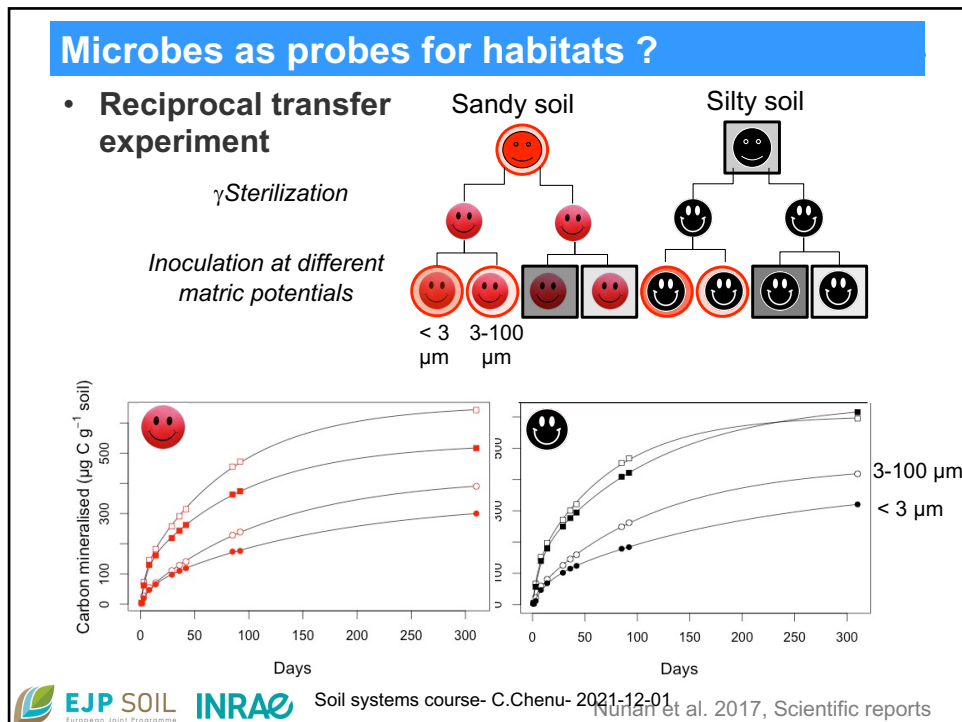
Water-filled pore ∅ range (μm)

Differences in activity: due to μ or local conditions?

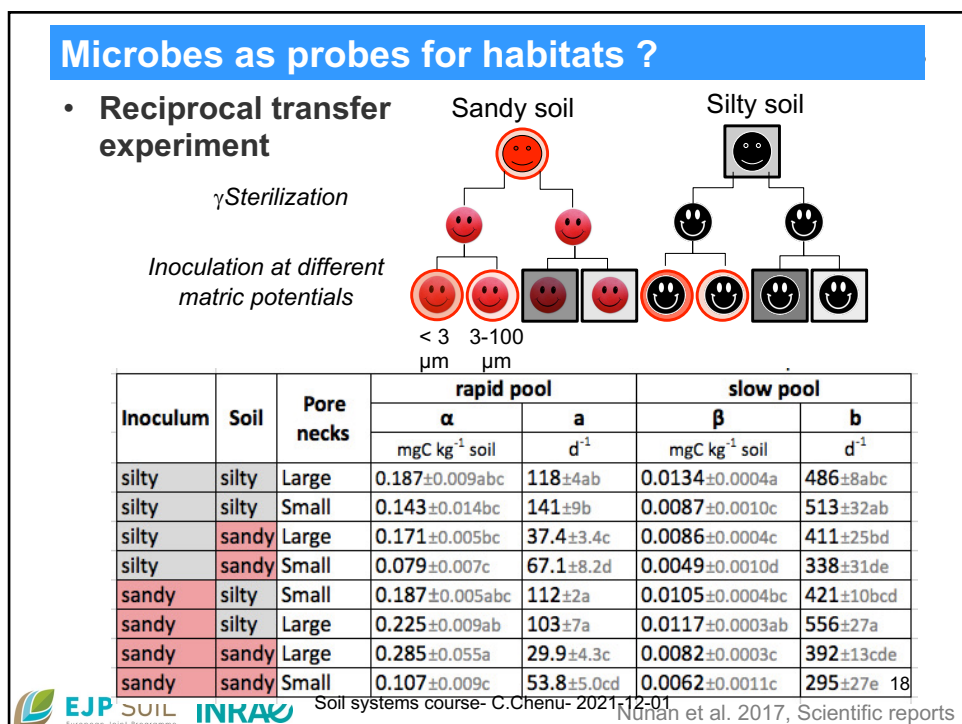



Ruamps et al. (2011) Soil Biol & Biochem

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Microbes as probes for habitats ?

- Reciprocal transfer experiment**
 - γ Sterilization
 - Inoculation at different matric potentials

Sandy soil

< 3 μm 3-100 μm

Silty soil

Inoculum	Soil	Pore	rapid pool		slow pool	
			α	a	β	b
			Correlated with inoculum soil, pores		Correlated with soil, pores	

➔ mineralisation of “slow” SOM controlled by habitat rather than by microbial community structure

➔ faster mineralisation rates in larger neck pores

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Indicators of soil structure controls on decomposition

- Pore-based approach**
 - “Local porosity” (350 μm shell)
Connection to macropores

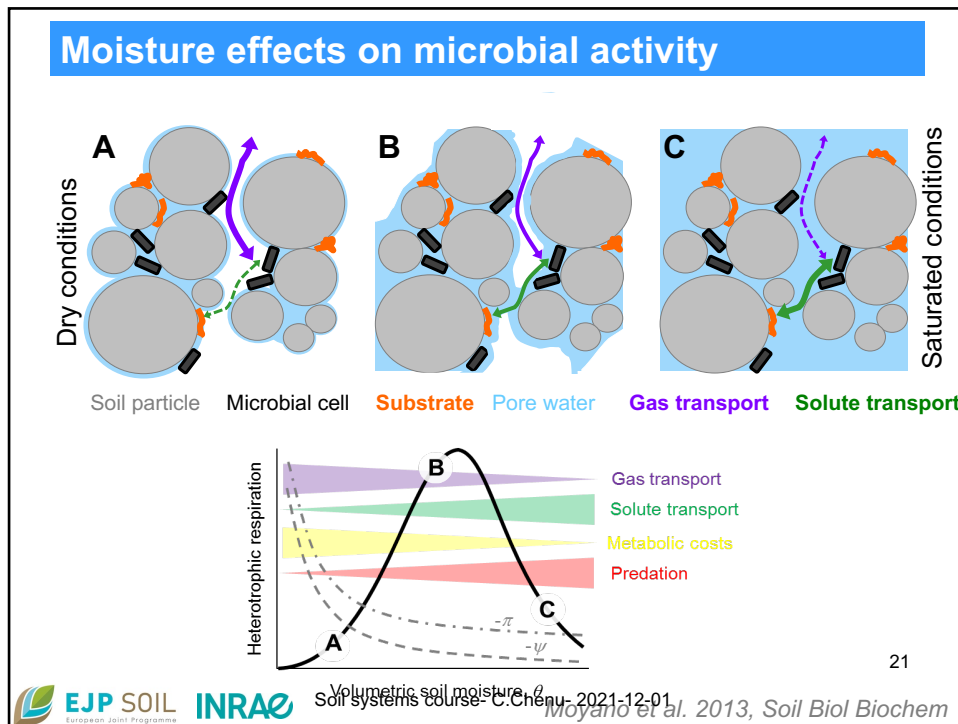
FIGURE 2 | Principles of local porosity and connectivity determination. An OM substrate particle centrally located in the mid square in a horizontal X-ray μ CT section of a soil core (A). Local porosity determination starts with selection of individual OM substrate particles (B). Next, a 3D shell (orange shaded area) surrounding (350 μ m in each direction) the OM substrate particle (green) is created (C). The fraction of pores located in the shell that are connected to large pores (> 300 μ m equivalent diameter) outside the shell (marked in red) is used as a measure of connectivity between local pore space and bulk soil (D). This process is repeated for all individual OM substrate particles (E) present in each soil core μ CT volume.

FIGURE 3 | Percentage of pores in the in the 350 μ m buffer zone around selected or grass substrate particles that are connected to large pores (equivalent diameter > 300 μ m in bulk soil for the substrate-N amended treatments for both “loose” and “dense” structured soils at 2% WFPS. Different means of structure treatments per substrate type are indicated by different capital letters.

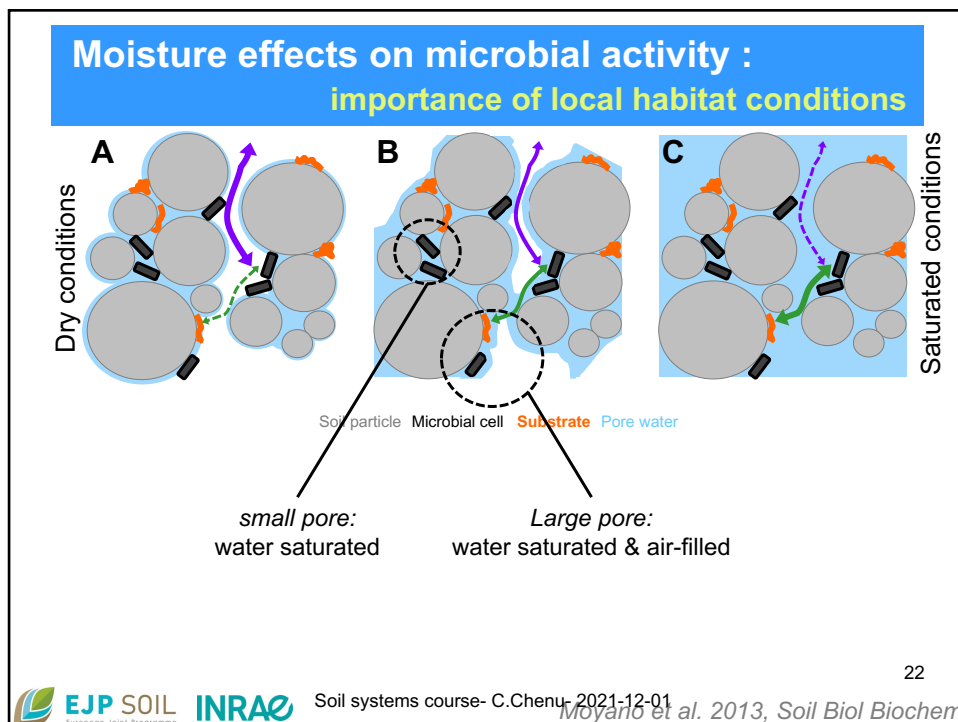
Maenhout et al. 2018, Frontiers

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Hot spots and hot moments

Soil volume

Process rate (h⁻¹)

Dead soil

Mean

Hotspots

« Hotspots are small volumes of soil with much **higher process rates** and intensive interactions compared to the average soil conditions »

Kuzyakov and Blagodatskay, 2015 SBB

Aggreg. surfaces

Detritosphere

Rhizosphere

Biopores

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A hot spot in soil...

OM

bacteria

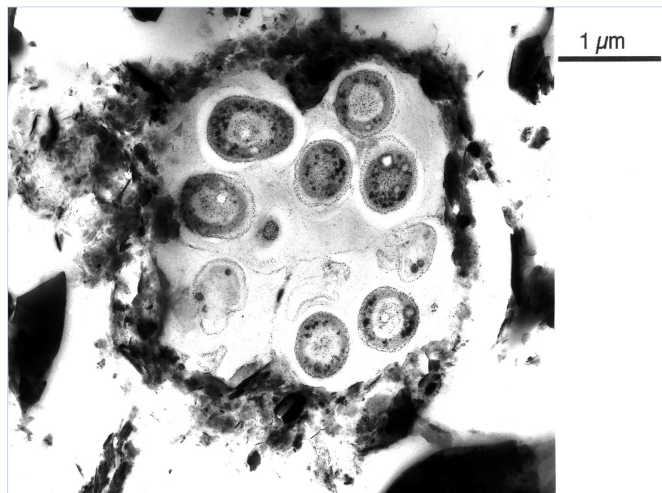
10 μm

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3- Feedbacks: effects of microorganisms on soil structure *(related to OM decomposition)*

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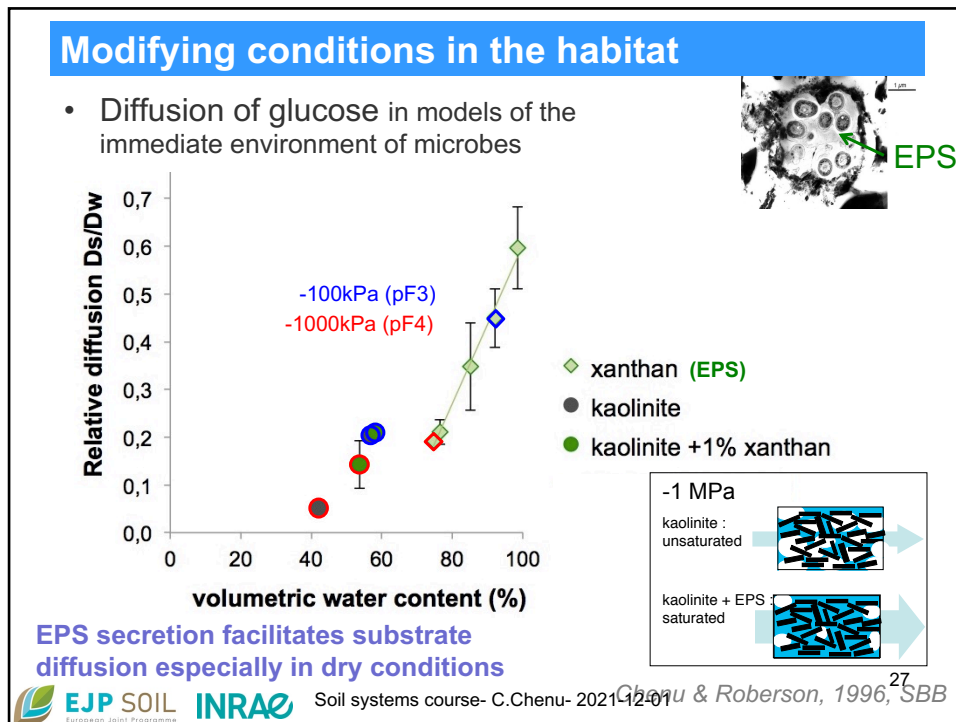
Bacterial microaggregate



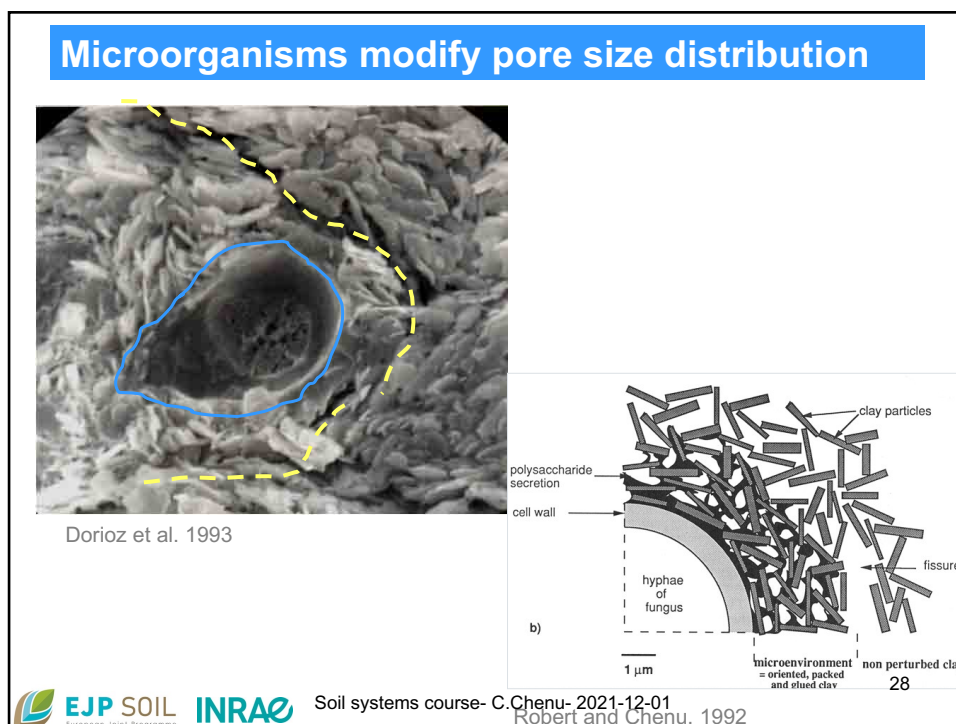
Transmission electron microscopy

Staining of polysaccharides with silver proteinate

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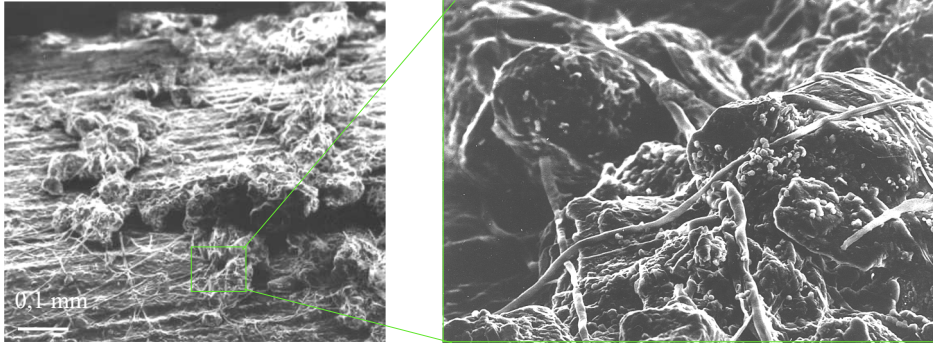


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Soil aggregation by microbial decomposers: physical entanglement



Angers & Chenu, 1998

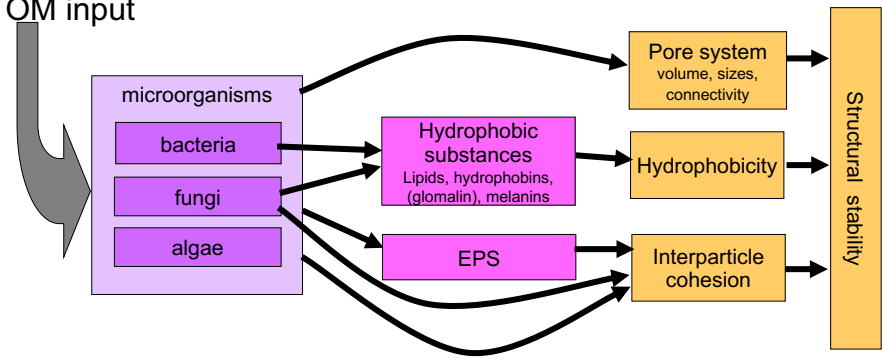



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Microbial controls on aggregate stability



Chenu & Cosentino, CABI 2011₃₀

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