UNIVERSITÀ DEGLI STUDI DI PADOVA

DAFNAE
Department of Agronomy Food Natural resources Animals Environment

UNDERSTANDING SOIL CARBON PROCESSES WITH THREE-DIMENSIONAL MODELS

N. Dal Ferro, F. Morari

Department of Agronomy Food Natural resources Animals Environment - University of Padova, Italy

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Soil functions

2015 International Year of Soils
fao.org/soils-2015

Soils deliver ecosystem services that enable life on Earth

Food and Agriculture Organization of the United Nations

with the support of

Schweizerische Eidgenossenschaft
Confédération suisse
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Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
Federal Office for Agriculture FOAG

Soil Threats in EU

Montanarella 2015 *Nature*


Most soils are in private ownership, making it tricky to implement binding international agreements.

Govern our soils

Luca Montanarella calls for a voluntary international agreement to protect the ground beneath our feet from erosion and degradation.

Eighty years ago, in 1935, soils were for the first time officially recognized as a limited national resource that should be responsibly managed. In the wake of the catastrophic erosion that caused the infamous Dust Bowl drought, the US government passed the Soil Conservation Act. "The history of every Nation is eventually written in the way in which it cares for its soil," wrote President Franklin D. Roosevelt.

Roosevelt's act was largely successful. It encouraged farmers to apply sustainable management practices — such as tilling less, installing windbreaks, and planting along slope contours[1]. Between 1982 and 2007, soil erosion in US cropland declined by 43% (ref. 2).

The history now being written in the world's soils is not so rosy. Every year, 75 billion tonnes of crop soil are lost worldwide to erosion by wind and water, and through agriculture; this costs about US$400 billion a year[3]. Only a few countries have national legislation protecting soil, including Germany and Switzerland[4]. Attempts at binding international legal agreements have so far failed.

This cannot go on. Soils are a limited natural resource, unequally divided between nations and people. They provide fertilizer for growing food; store and filter water; host rich ecosystems, including many little-known species; provide resources such as peat, sand, clay and gravel; and hold our cultural and historical memory in archaeological artefacts. The ground beneath our feet is a public good and service.

GET OFF MY LAND

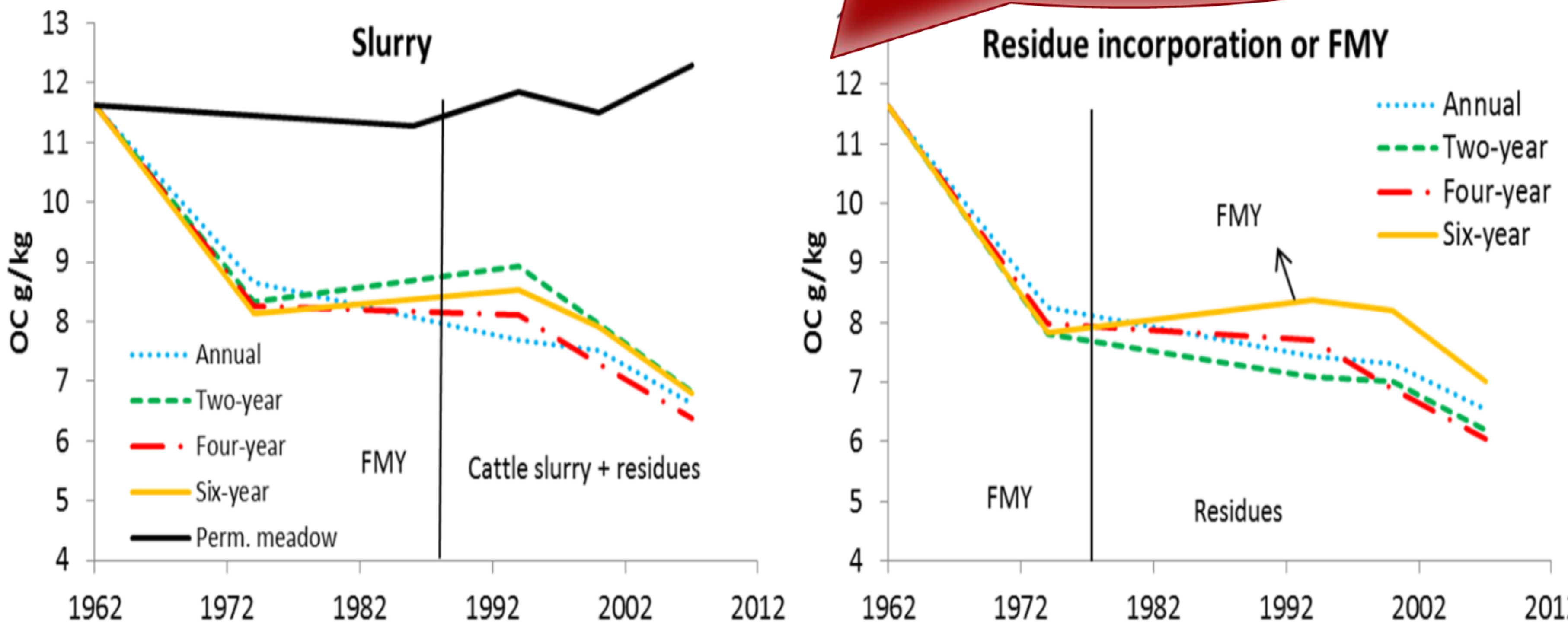
Without governance to assure wise management and equitable access, we are heading towards increased poverty, hunger, conflict, land grabs and mass migration of displaced populations, such as that seen during the Great Depression[5]. The world now stands at a moment of opportunity. A Global Soil Partnership (GSP) exists, and could implement a voluntary system of global governance. But the GSP needs to develop clear, concrete proposals for action to secure more funding and move forwards.

International soil governance faces great challenges. Take, for example, a nearly decade-long attempt by the European Union to implement a governance framework. A team at the European Commission (of which I was part) developed a common EU strategy for soil protection[6] including a proposed EU Soil Framework Directive, which would have obliged member states to take action to prevent soil degradation. It was the result of several years of consultations in specialized working groups that included scientists, policymakers, industry representatives, landowners and farmers, as well as concerned non-governmental organizations (NGOs) and other stakeholders. Much was at stake, including the ongoing, costly remediation of more than 3 million contaminated sites in Europe, such as old industrial areas and mining sites, and the question of who should pay.

Several EU member states opposed the directive. Their arguments were much the same as those used in 1935 by opponents to the US Soil Conservation Act. They countered that soils are a strictly local issue, and should be governed locally rather than

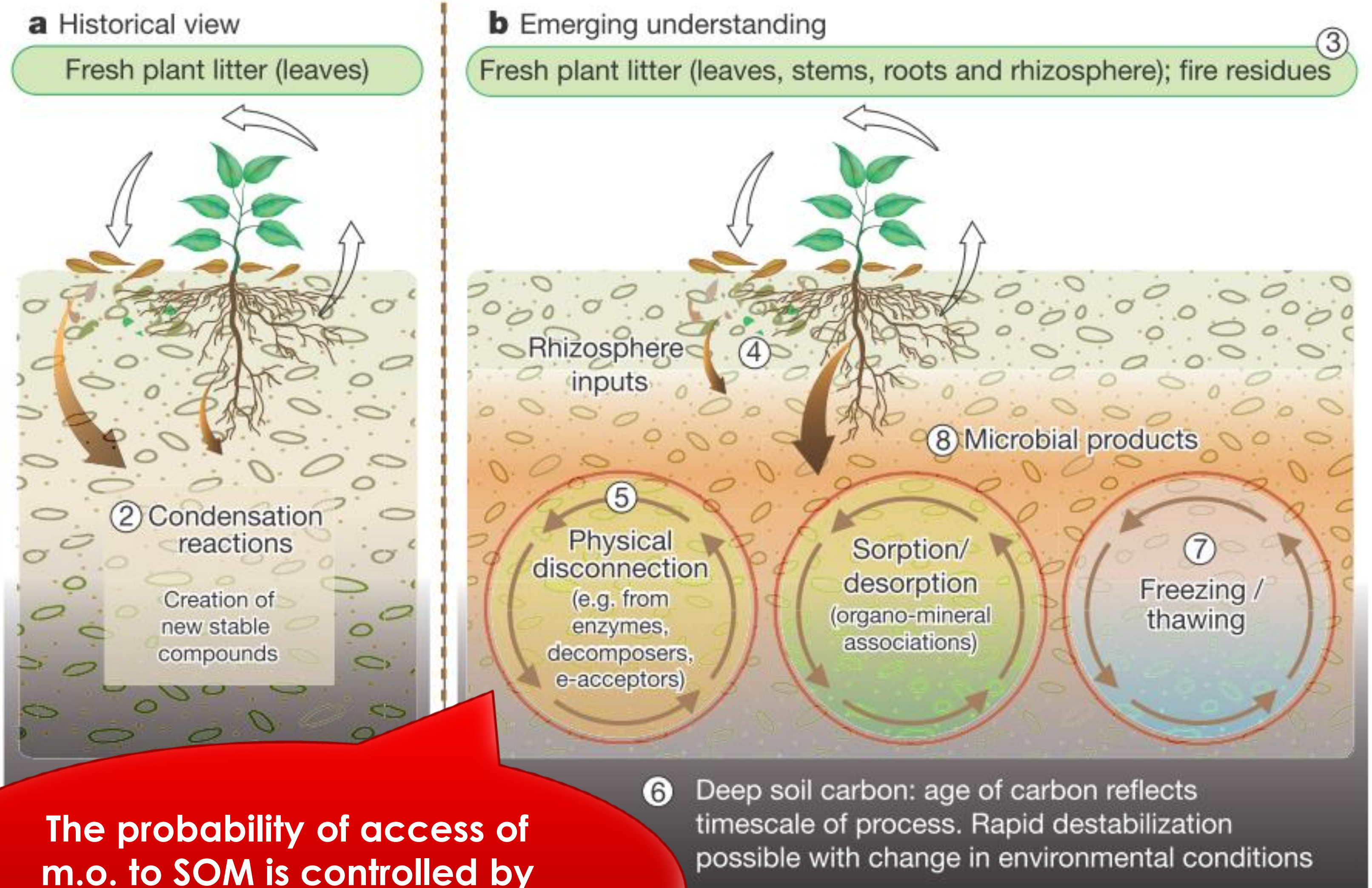
STATUS OF SOM IN NE ITALY

In the last 50 years, SOM in northeastern Italy decreased at rates of 0.02-0.58 t C ha^{-1} y^{-1}



Berti et al. 2016 *Eur. J. Agron.*

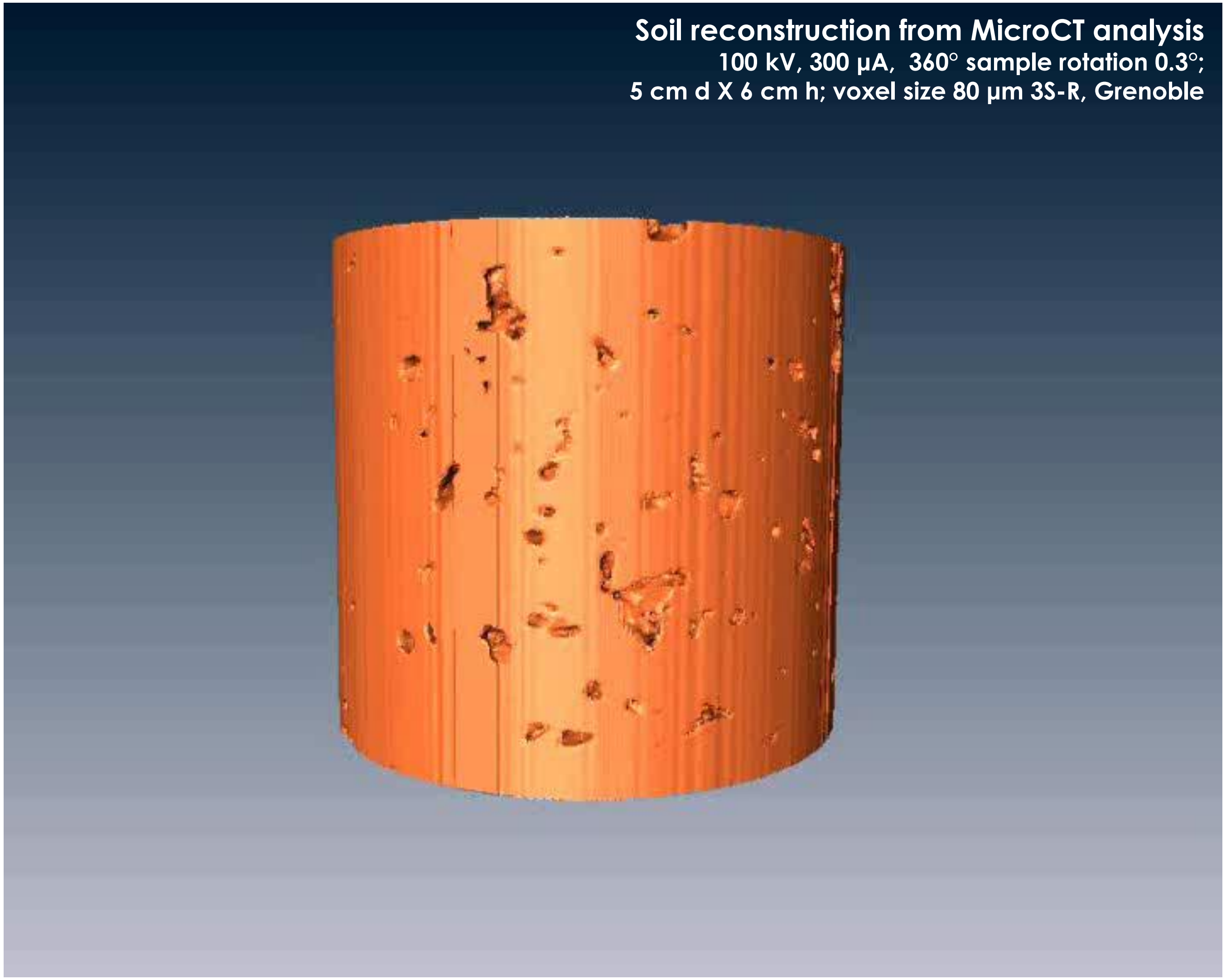
SOM Dynamics - what do we know?



Schmidt et al. 2011 *Nature*

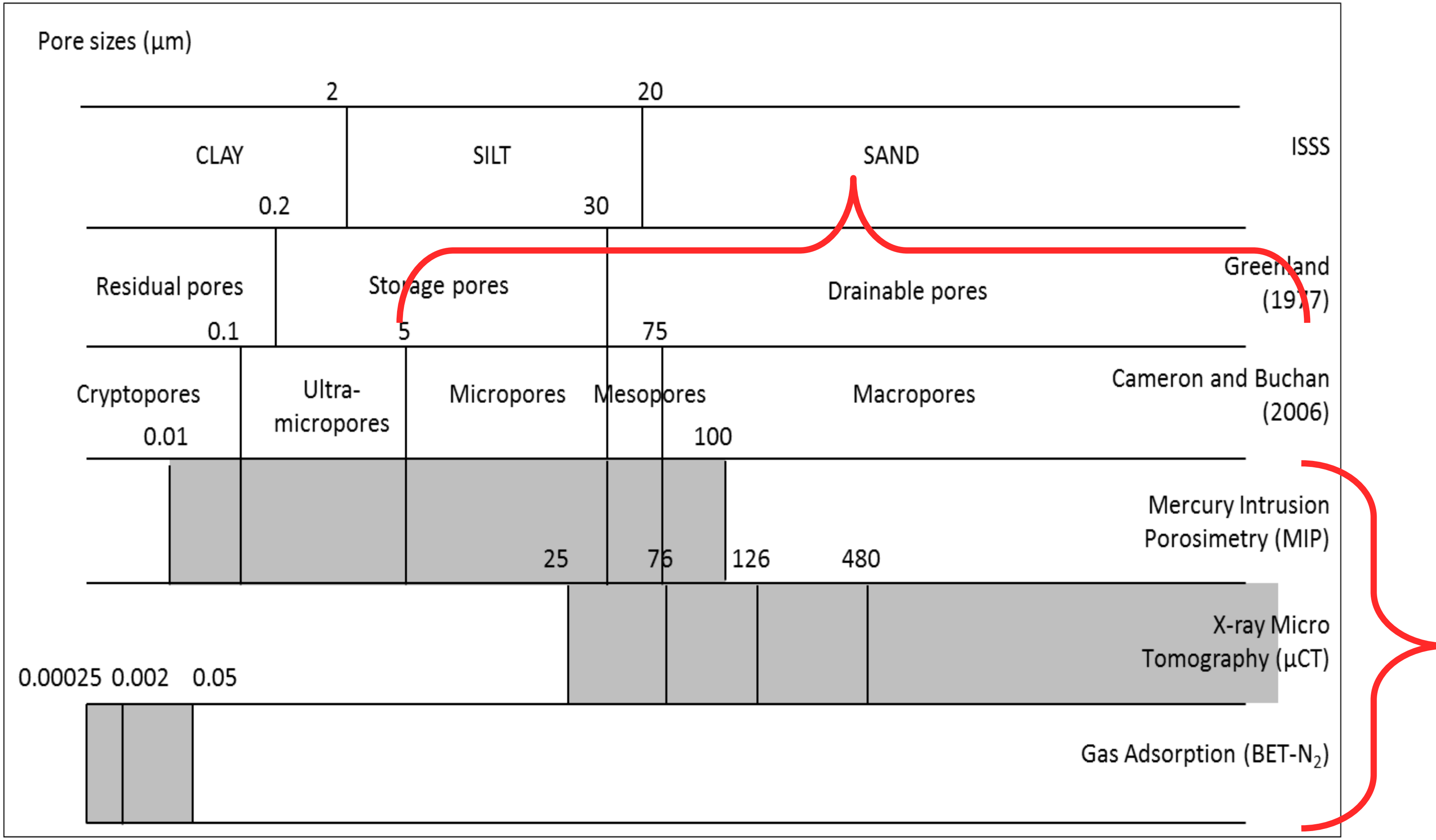
The probability of access of m.o. to SOM is controlled by biological, chemical and physical variables

SOM DYNAMICS - WHAT DO WE KNOW?



Data on microbial accessibility to pore systems are becoming available

Soil Pore Functions and Scales



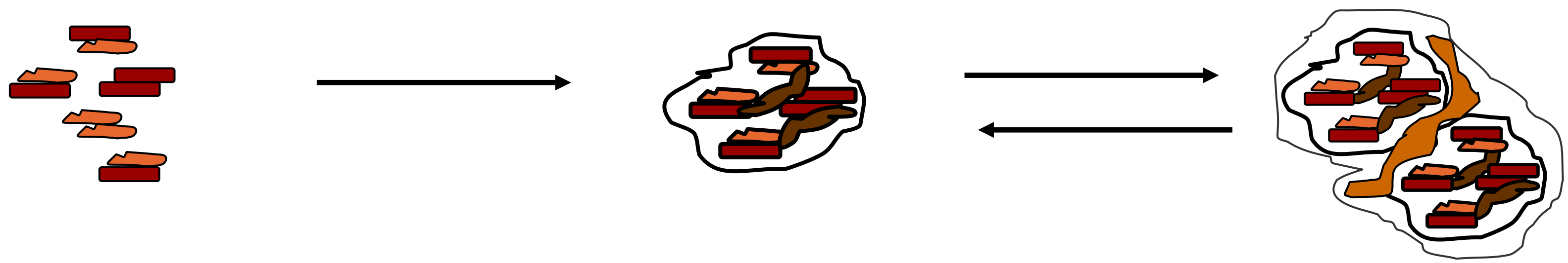
Pituello et al. 2016 *Agric. Ecosyst. Environ.*

AGGREGATE STABILITY & SOC PROTECTION

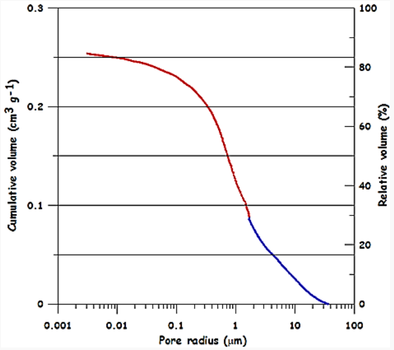
AGGREGATE HIERARCHY CONCEPT

Tisdall and Oades (1982) and successive integration

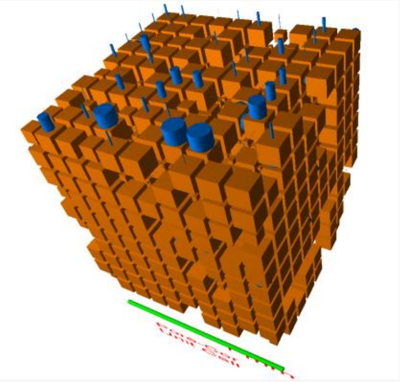
Primary particles <53 µm | **Microaggregates 53 -250 µm** | **Macroaggregates >250 µm**



Aggregates 1-2 mm



MIP (< 100 µm)



3D Network models

3D-Model of Water Infiltration in Aggregates

Aggregate breakdown is reduced due to SOC effects

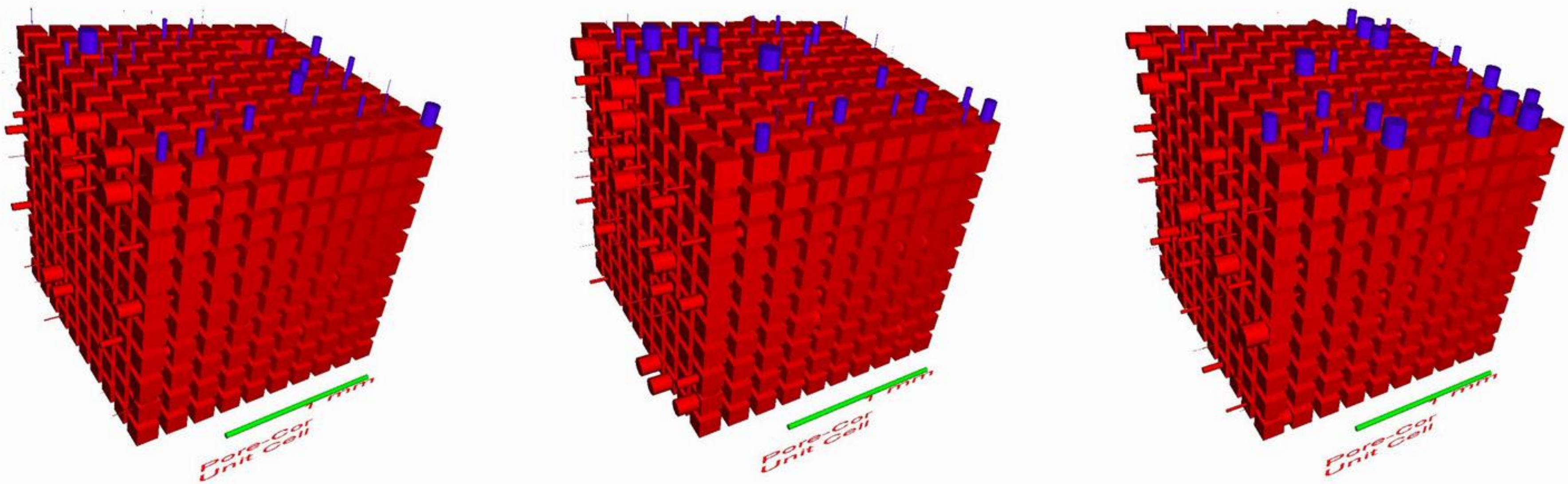
+ Interparticle cohesion of aggregates

+ Hydrophobicity

- Macropores **(> 5 µm) + micro**pores **(< 5 µm)**

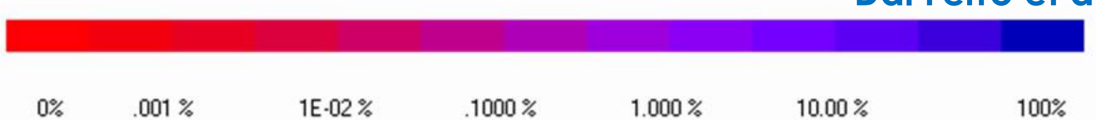
50 years of…

Organic fertilization | Mineral fertilization | No fertilization



Dal Ferro et al. 2012 *Eur. J. Soil Sci.*

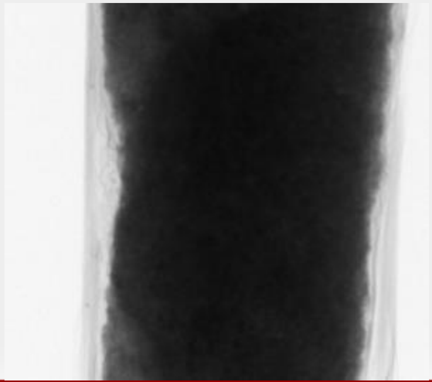
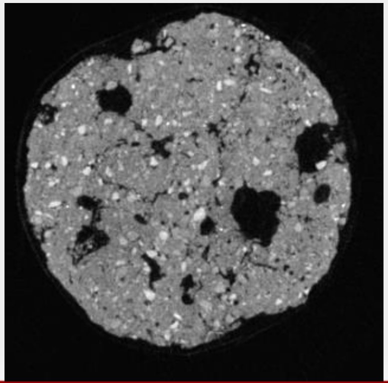
Degree of wetting



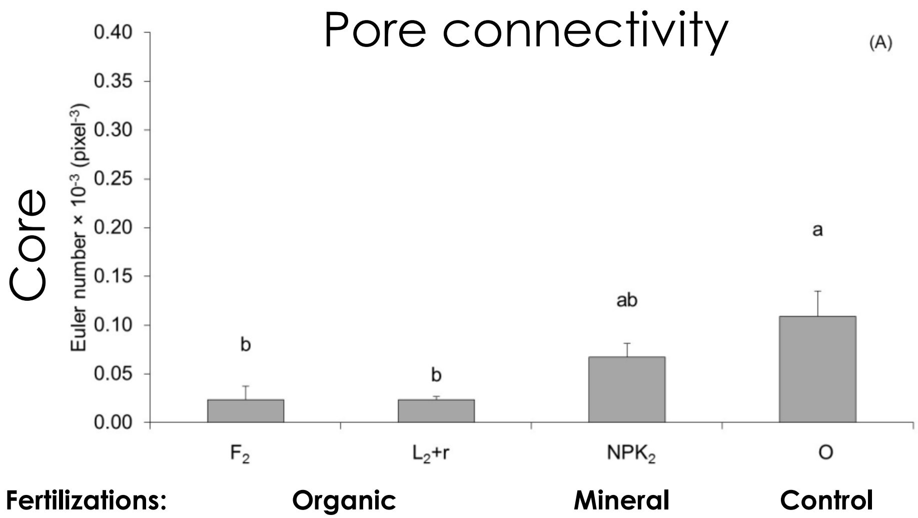
SOC Dynamics at Larger Pore Scale

X-ray microtomography:

- Non-destrictuve analysis
- Renders soils «transparent»
- 3D images at fine resolution (µm scale)
- Extensive data of different soil phases
- Both soil cores and aggregates analysed

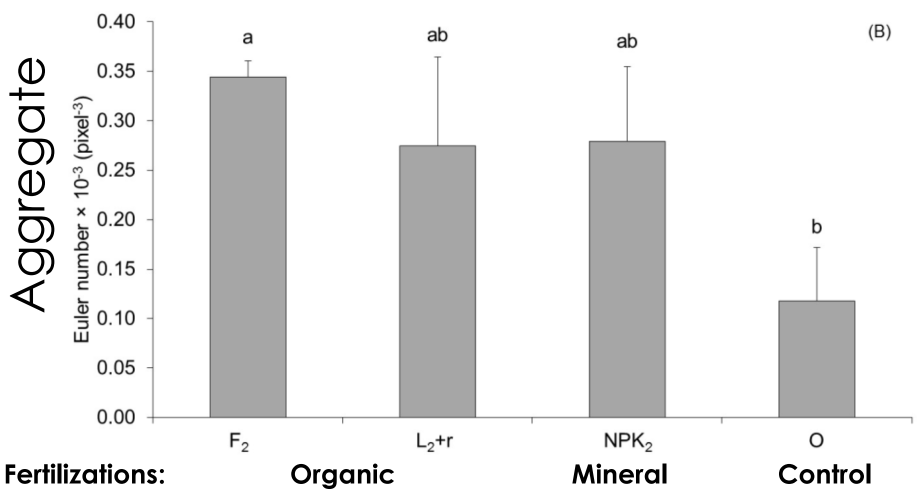




DIFFERENT SCALES: DIFFERENT MECHANISMS?



Inter-aggregate scale
SOC enhances soil core structure improving pore connectivity

Increase of pores > 550 μm



Intra-aggregate scale
SOC decreases connectivity

No data on pores < 10 μm

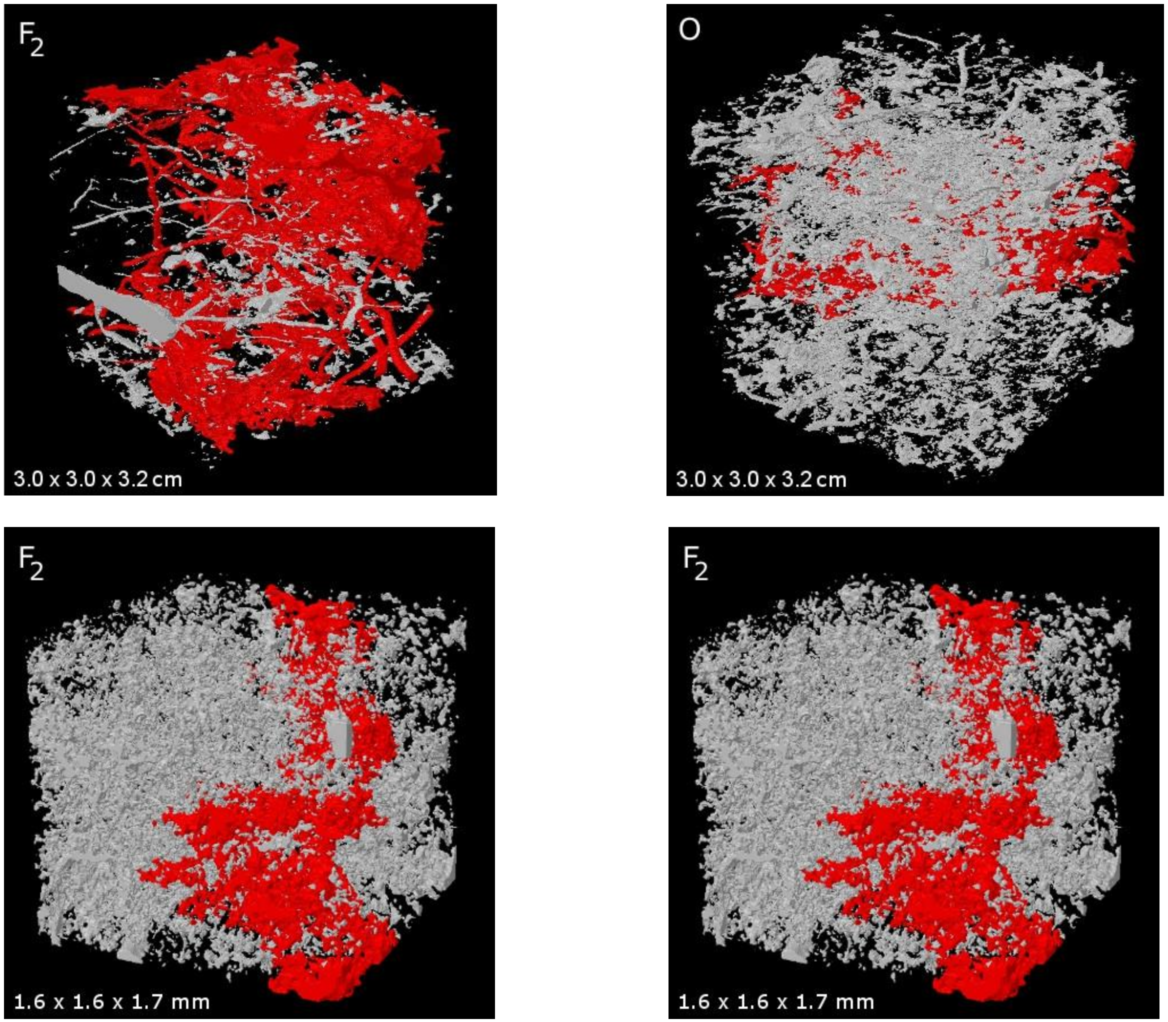
Dal Ferro et al. 2013 *Geoderma*

DIFFERENT SCALES: DIFFERENT MECHANISMS?

Organic fertilization | Control

Soil Cores

Soil aggregates



LINKING INFORMATION FROM DIFFERENT SCALES

Conceptual models on SOC processes are still needed to better understand C dynamics

Combining information on micro-heterogeneity with other experimental measures

- gas fluxes
- m.o. movement (only pores > 5 µm are accessible)
- fungi growth

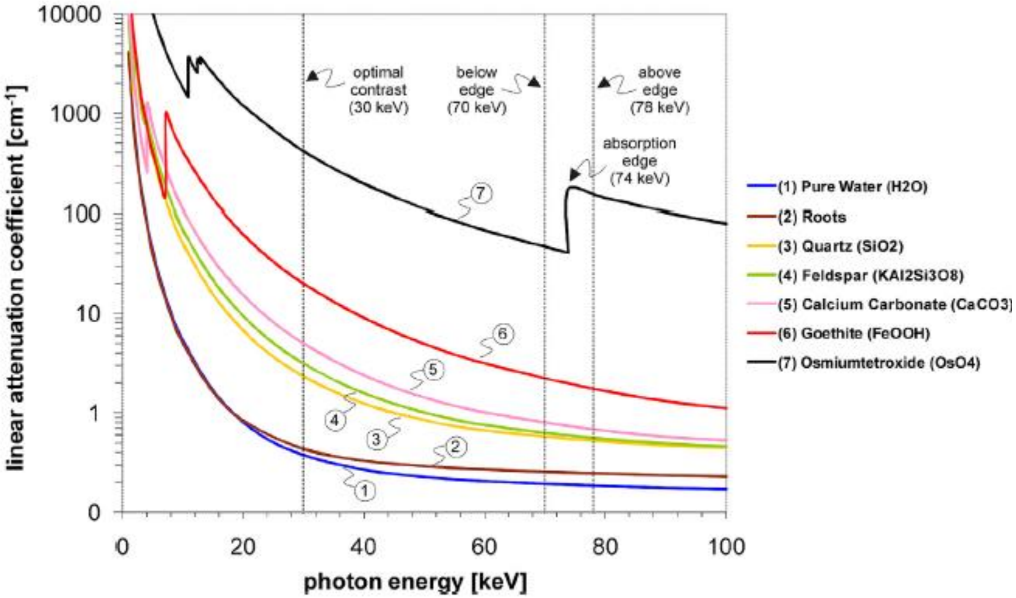
Kravchenko & Guber 2016 *Geoderma*

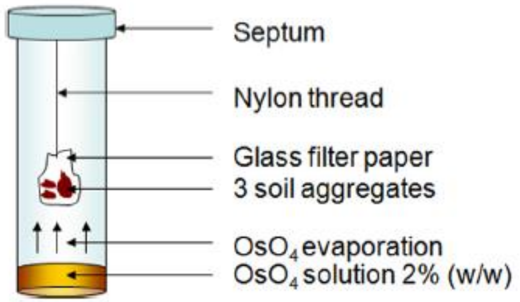
It is essential to quantify the «routes» by which substrates are accessed, where they are and how are accessed

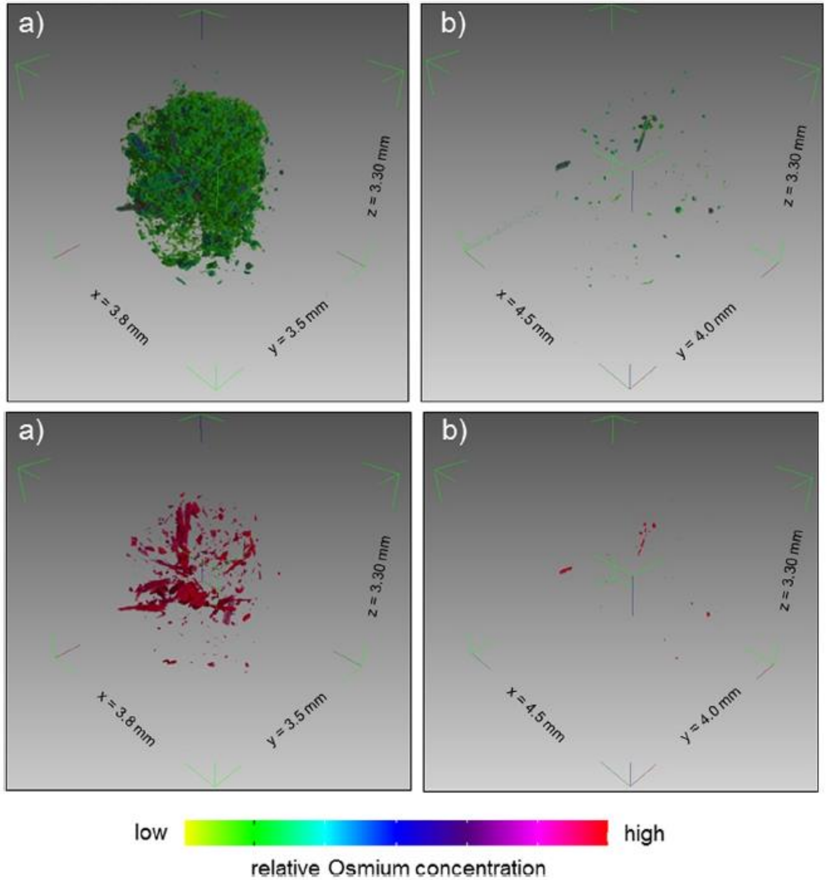
Lehman & Kleber 2015 *Nature*

Advancements on SOC Localization

Synchrotron-based experiments



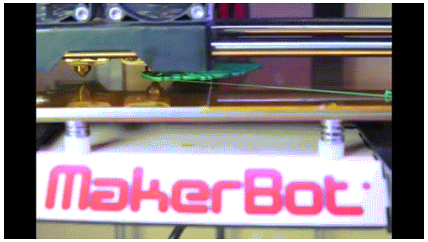




Peth et al. 2014 *Soil Biol. Biochem*

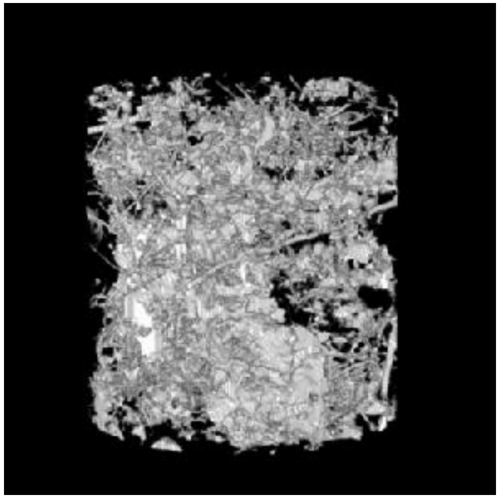
3D Physical Models

3D printer

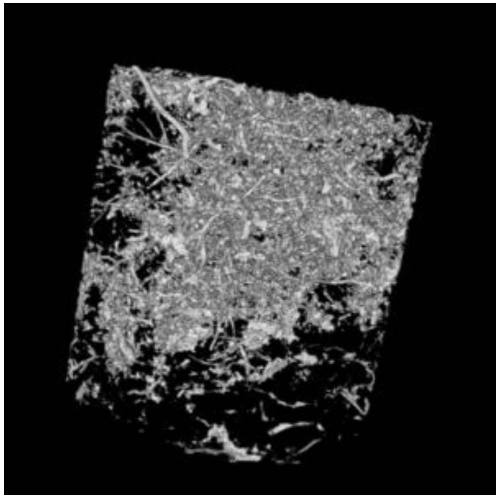


Pore network from microCT | **3D-printed soils** (2.4 cm d x 2.4 cm h)

Organic fertilization



Control



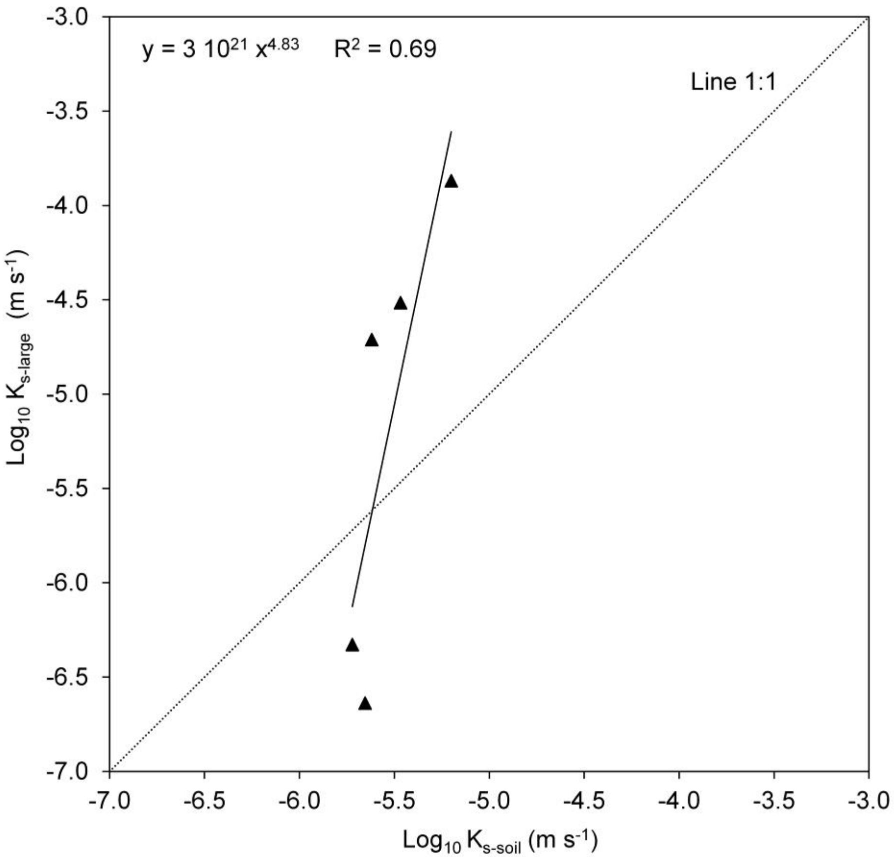
3D PHYSICAL MODELS

Soil

B&W image

Prototype

Saturated hydraulic conductivity



Future perspectives

Separate physical and chemical processes

Design synthetic pore systems with peculiar characteristics

Define specific distance from substrate to m.o./fungi

Dal Ferro & Morari 2015 *SSSAJ*

Conclusions

The persistence of soil organic carbon is primarily an ecosystem property, not a molecular property

Advanced tools for studying soil C processes are (almost?) ready

Different techniques and approaches are necessary to characterize the soil structure for SOC studies

A major challenge to fully understand SOC dynamics is making compatible biogeochemical information from multi-scale analyses

Thanks for your attention

Contacts: nicola.dalferro@unipd.it