Promoting carbon sequestration in soils: The 4 per 1000 initiative

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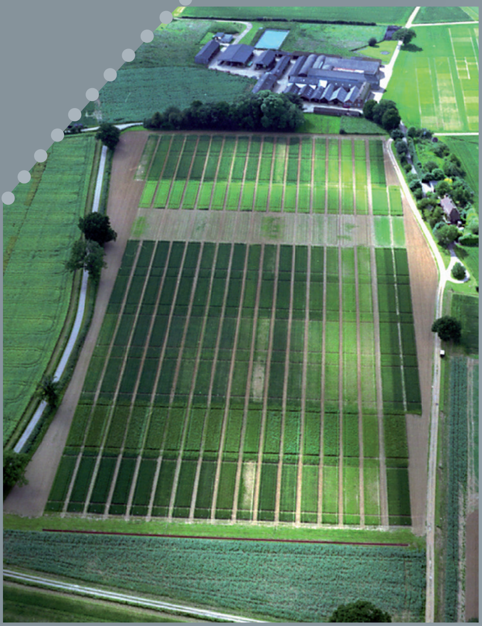

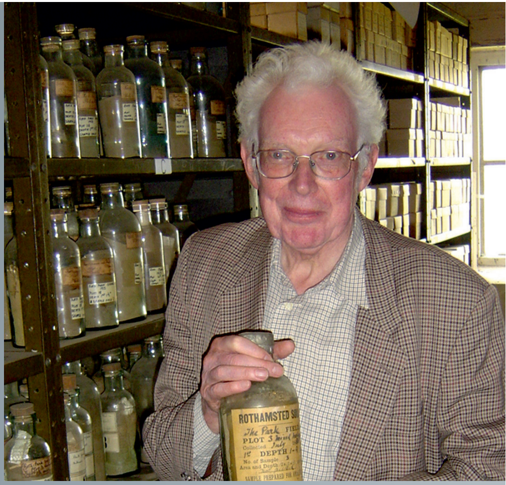

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ROTHAMSTED RESEARCH

ABSTRACTS

O-2b.08

C-MIP: An international model inter-comparison simulating organic carbon dynamics in bare fallow soils

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Introduction

C sequestration in agricultural soils contributes to the achievement of the climate objectives (e.g. COP-21"s "4 per 1000" initiative). Reliable methodologies are needed to assess the soil C sequestration potential of agricultural lands in different management, soil and climate conditions. Simulation models extrapolate C dynamics from current knowledge in both time and space. This is difficult when soil is covered by vegetation, for the continuous input of plant residues and root exudates, and the influence of plants on soil water and temperature dynamics. Long-term bare fallow (LTBF) experiments offer ideal conditions to test models simulating soil organic C dynamics.

Objectives

The aim is to assess the ability of a set of models to simulate soil C dynamics on LTBF experiments, with particular reference to recalcitrant pools.

O-2b.12

Unravelling complexity of biophysical interactions in soil: linking fungal traits, pore geometry and distribution of soil organic matter hotspots to explain evolution of CO_2.

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Soil structure provides a home to large numbers of microorganisms offering them a food base, support, access to water, air and nutrients and protection from predators. To be able to function, soils need to deliver these essential requirements for life, at micro-habitat scales. Soil structure is the soil characteristic that makes this possible. Therefore, soil structure holds the key to life in soil, regulates many ecosystem services and ultimately underpins sustainable life on Earth. Despite this, the exact way in which soil structure exerts its control is not fully understood and considered to be too complex to be explicitly included in modelling of key processes such as SOM dynamics.

In this study we ask: *can we develop a predictive framework for fungal ecology in heterogeneous soil that bridges scales, and what benefits would it bring?*

To address this question we developed a model that considers fungal interactions at scales directly relevant to the organisms (micro-meters) in order to predict ecosystem services, such as the evolution of CO2, as an emergent property of these interactions. The model is based on fungal traits, and explores through scenario modelling how these impact upon exploration of pore networks as determined by X-ray CT, and how this is affected by the location of particulate organic matter and the distribution of water within the pore space. The model predicted two important behaviours that are not captured by other models: (i) the evolution of CO_2 increases in a non-linear way with increasing organic matter content. This response suggests a critical behaviour could be expected in microbial processes involved in the decomposition of SOM; (ii) the same amount of SOM in a soil sample (e.g. represented as a bulk property) can lead to substantial different CO_2 evolutions, predicted to differing by a factor 200, depending on the spatial distribution and accessibility within the soil structure. This is the first modelling framework that is capable of combining fungal dynamics in structured soil with SOM dynamics and evolution of CO_2. The advantage of the modelling approach is that scenarios can be rapidly explored beyond what is experimentally tractable, and as such can explore parameter spaces where soil functioning and biodiversity may be resilient to change, and can guide further experimental testing.

O-2c.10

High organic inputs explain shallow and deep SOC storage in a long-term agroforestry system – Combining experimental and modeling approaches.

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Question

In temperate agroforestry systems, soil organic carbon (SOC) stocks are generally increased [**1**], but is difficult to disentangle the different factors responsible for this SOC storage. Organic carbon (OC) inputs to soil may be larger, but SOC decomposition rates may also be modified owing to physical protection, microclimate, or priming effect from tree roots. Our objective was therefore to assess if organic inputs could be the main driver of SOC storage in agroforestry systems.

Methods

This study was performed in an 18-year-old silvoarable system associating hybrid walnut trees and durum wheat, and in an adjacent agricultural control plot. SOC stocks and all OC inputs to the soil, i.e., leaf litter, tree fine root senescence **[2,3]**, crop residues, and tree row herbaceous vegetation were quantified down 2 m depth **[4]**. We then adapted a model **[5]** to simulate SOC dynamics in agroforestry accounting for both the whole soil profile and the lateral spatial heterogeneity.

Results

Measured OC inputs to soil were increased by about 40% (+ 1.11 t C ha^{-1} yr^{-1}) down 2 m depth in the agroforestry plot compared to the control, resulting in an additional SOC stock of 6.3 t C ha^{-1} down to 1 m depth (Fig. 1). The model described properly the measured SOC stocks and distribution with depth, especially when priming effect was taken into account (Fig. 2).

Conclusions

Modeling showed that the observed SOC storage in an agroforestry system would result from increased OC inputs, which were measured, and from an acceleration of SOC decomposition. This compensatory mechanism could reduce a lot the potential of agroforestry soils to store SOC, especially at depth. Deep-rooted trees modify OC inputs to soil, a process that deserves further studies given its potential effects on SOC dynamics.

References

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Figures

Figure 1. Measured SOC stocks and OC inputs to the soil a) in the agricultural control plot, b) in the 18-year-old agroforestry plot.

Figure 2. Measured and modeled soil organic carbon contents (kg C m^{-3}) in an agricultural control plot and in an 18-year-old silvoarable system with a two pools model without priming effect (no *PE*), with a two pools model with priming effect (*PE*) and with a three pools model without *PE*.

Figure 1

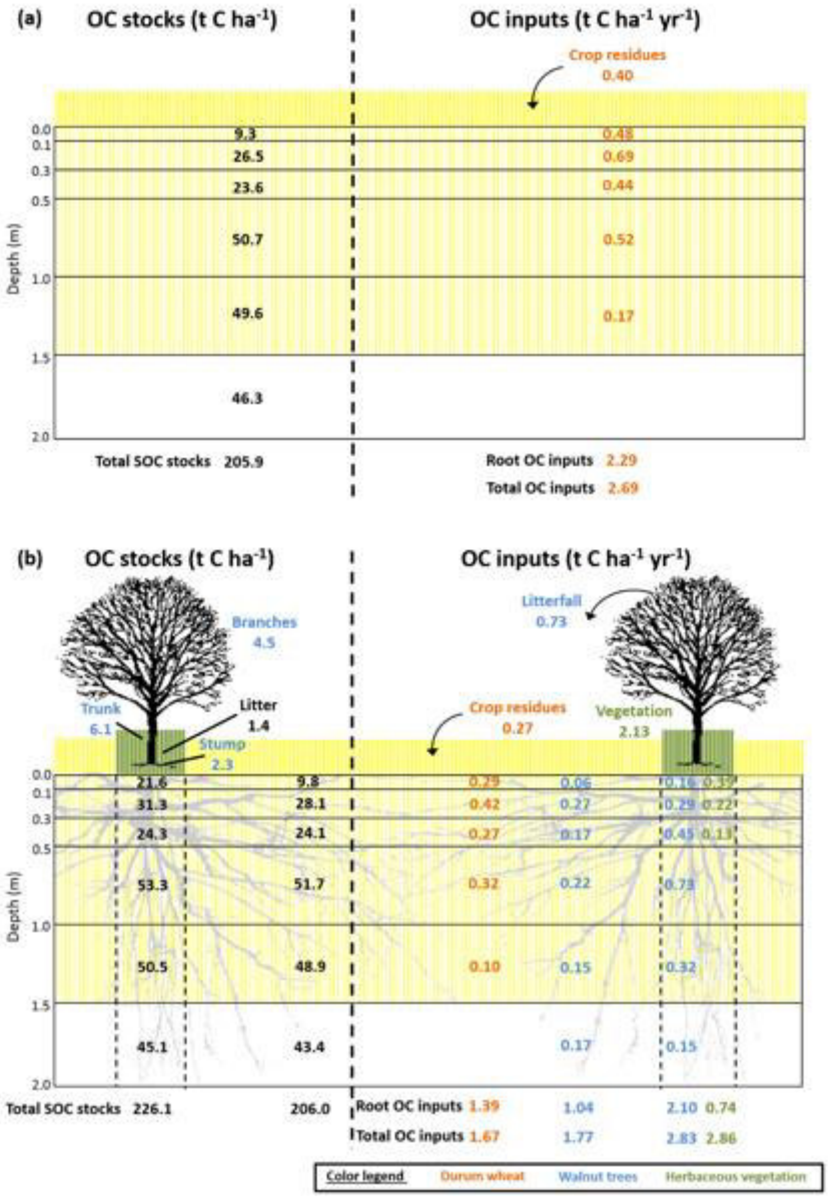
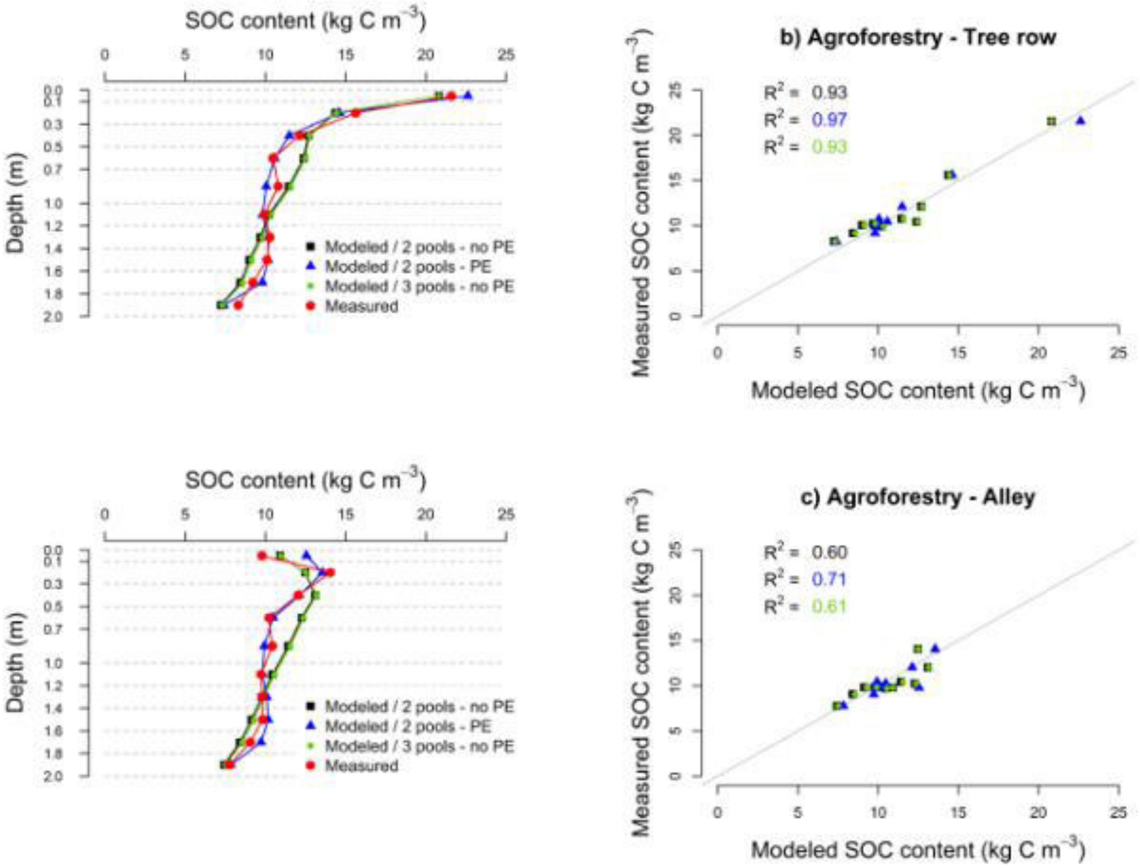

(a)
OC stocks (t C ha-1)
OC inputs (t C ha-1 yr-1)
Crop residues
0.40
Depth (m)
0.0
0.1
0.3
0.5
1.0
1.5
2.0
9.3
26.5
23.6
50.7
49.6
46.3
0.48
0.69
0.44
0.52
0.17
Total SOC stocks 205.9
Root OC inputs 2.29
Total OC inputs 2.69
(b)
OC stocks (t C ha-1)
OC inputs (t C ha-1 yr-1)
Branches
4.5
Trunk
6.1
Litter
1.4
Stump
2.3
Litterfall
0.73
Crop residues
0.27
Vegetation
2.13
Depth (m)
0.0
0.1
0.3
0.5
1.0
1.5
2.0
21.6
31.3
24.3
53.3
50.5
45.1
9.8
28.1
24.1
51.7
48.9
43.4
0.29
0.42
0.27
0.32
0.10
0.06
0.27
0.17
0.22
0.15
0.17
0.16 0.39
0.29 0.22
0.45 0.13
0.73
0.32
0.15
Total SOC stocks 226.1
206.0
Root OC inputs 1.39
1.04
2.10 0.74
Total OC inputs 1.67
1.77
2.83 2.86
Color legend
Durum wheat
Walnut trees
Herbaceous vegetation

Figure 2


SOC content (kg C m-3)
0
5
10
15
20
25
Depth (m)
0.0
0.1
0.3
0.5
0.7
1.0
1.2
1.4
1.6
1.8
2.0
■ Modeled / 2 pools - no PE
▲ Modeled / 2 pools - PE
● Modeled / 3 pools - no PE
● Measured
b) Agroforestry - Tree row
R² = 0.93
R² = 0.97
R² = 0.93
Measured SOC content (kg C m-3)
Modeled SOC content (kg C m-3)
SOC content (kg C m-3)
Depth (m)
■ Modeled / 2 pools - no PE
▲ Modeled / 2 pools - PE
● Modeled / 3 pools - no PE
● Measured
c) Agroforestry - Alley
R² = 0.60
R² = 0.71
R² = 0.61
Measured SOC content (kg C m-3)
Modeled SOC content (kg C m-3)

O-3a.02

Multidecadal persistence of organic matter in soils: Insights from STXM-NEXAFS and nano-SIMS investigations

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The mineral matrix and clays in particular protect soil organic matter (SOM) from decomposition by micro-organisms. Better understanding the mechanisms responsible for the pluri-decadal persistence of carbon in soils requires constraining the dynamics, the distribution and the chemical nature of both SOM and associated mineral phases. Benefiting from the unique opportunity offered by a long-term bare fallow (LTBF) experiment having started in 1928 in Versailles (France), we report C and N decline with time for six different particle-size fractions (sand [>50µm], coarse silt [20-50µm], fine silt [2-20µm], coarse clays [0.2-2µm], intermediate clays [0.05-0.2µm] and fine clays [0-0.05µm]). We also report spatially resolved characterization at the submicrometer scale of SOC dynamics using STXM-based NEXAFS and nano-SIMS. As expected, total C and N declined with time in all fractions. The lowest declines were observed for intermediate size clays [0.05-0.2µm] in which only 53 % of C and 63% of N were lost between the initiation of the bare fallow and 2008. C/N ratios of SOM associated to clays significantly decreased with time whereas C/N ratios of SOM associated to silt fractions remained constant. SOM associated to intermediate and fine clays were notably very low (below 5) after 8 decades of bare fallow. Bulk-scale C-NEXAFS data reveals that the speciation of SOC remained almost constant with LTBF duration. STXM-based NEXAFS investigations at the submicrometer scale revealed that all smectitic clays were associated to OM coatings at all dates whereas illite particles became progressively SOM-free with increasing bare fallow duration. STXM-based NEXAFS investigations also revealed that particles of organic matter can be observed within the coarse clay fractions even after 8 decades of bare fallow. Nano-SIMS investigations on bulk clay fractions showed that OM decline was similar for Si-, Al- and Fe-rich regions. Our study provides new lines of evidence for the higher protection of N-rich SOM by minerals and is the first direct observation of the specific ability of smectites to protect SOM at a pluri-decadal timescale.

O-3b.11

Effects of depth, soil and vegetation types on indicators of soil organic carbon lability in forest soils

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Soil organic matter is a key property as it influences soil ecosystem services like productivity, water storage, etc. In particular, the labile soil organic carbon (SOC) fraction plays a central role in short- to medium-term nutrient availability and soil structural stability. There is little evidence to differentiate the relative importance of factors influencing the labile SOC fraction in contrasted pedological and vegetation conditions. Soil respiration tests and particulate organic matter (POM) obtained by different fractionation schemes are considered as classical indicators of the labile soil organic carbon (SOC) pool. Thermal analyses, in particular Rock-Eval 6 (RE6) analysis, have also shown promising results in the determination of SOC biogeochemical stability.

Using a large set of samples of French forest soils representing contrasted pedoclimatic conditions we assessed the effects of depth (n = 5; up to 1 m), soil class (entic Podzol; dystric Cambisol; Calcisol) and vegetation types (deciduous; coniferous) on SOC biogeochemical and thermal stability. We explored how respired-C isolated by a 10-week laboratory soil respiration test, POM-C isolated by a physical SOC fractionation scheme (particle-size > 50 µm and $d < 1.6$ $g{\cdot}cm^{-3}$) and four RE6 parameters, correlated to short- or long-term SOC persistence, evolved in a set of 233 soils samples from 53 forest sites. Results showed that depth was the dominant discriminating factor, affecting significantly all parameters. With depth, we observed a decrease of both classical labile SOC indicators and the thermally labile SOC pool and an increase of the thermally stable SOC pool, along with an oxidation and a depletion of hydrogen-rich moieties of the SOC. Soil class and vegetation type had contrasted effects. For instance, entic Podzols and dystric Cambisols had relatively more thermally stable SOC in the deepest layer than Calcisols but more labile SOC in the surface layer than Calcisols. Soils in deciduous stands tend to contain a higher proportion of thermally stable SOC than soils in coniferous stands. This study shows that both vegetation and soil types influenced SOC stability at various depths and thus should be considered when mapping soil climate regulation ecosystem service.

P-3b.06

Is Rock-Eval 6 thermal analysis a good indicator of soil organic carbon lability? – A method comparison study in forest soils

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Soil respiration tests and particulate organic matter (POM) obtained by different fractionation schemes are considered as classical indicators of the labile soil organic carbon (SOC) pool. However, there is still no widely accepted standard method to assess SOC lability and the pertinence of these two time-consuming methods to characterize SOC turnover can be questioned. Alternate ways of determining the labile SOC component are thus well-needed. Thermal analyses, in particular Rock-Eval 6 (RE6) analysis has shown promising results in the determination of SOC biogeochemical stability. Using a large set of samples of French forest soils representing contrasted pedoclimatic conditions, including deep samples, we compared three different techniques used for SOC lability assessment. We explored whether respired-C isolated by a 10-week laboratory soil respiration test, POM-C isolated by a physical SOC fractionation scheme (particle-size > 50 µm and d < 1.6 g·cm^{-3}) and several RE6 parameters were comparable and how they correlated. As expected, respired-C and POM-C fractions strongly decreased with depth. RE6 parameters showed that SOC from deeper soil layers was also thermally less labile, more oxidized and H-depleted. Indeed, SOC from deeper soil layers had lower $C_L + C_I$ (proportion of thermally labile SOC), higher $T_{50\_HC\_PYR}$ (temperature at which 50% of the pyrolizable hydrocarbons were effectively pyrolyzed), larger oxygen index, and smaller hydrogen index. Surprisingly, the two classical indicators of the labile SOC pool (respired-C and POM-C) were only marginally correlated ($p = 0.051$) and showed layer-specific correlation. Similarly, respired-C was poorly correlated to RE6 parameters. The POM-C fraction showed a strong negative correlation with $T_{50\_HC\_PYR}$ ($\rho = -0.73$) and good correlations with other RE6 parameters.

Our study showed that RE6 parameters were good estimates of the POM-C fraction, which represents a labile SOC pool (residence time of *ca.* a couple decades) that is meaningful regarding SOC stock changes upon modifications in land management. RE6 thermal analysis could therefore be a fast and cost-effective alternative to more time-consuming methods used in SOC pool determination, and may be integrated into soil monitoring networks to provide high-throughput information on SOC dynamics.

P-3b.19

Organic carbon mineralization rates with depth in a calcareous soil under an agroforestry system

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Agroforestry systems, i.e. agroecosystems in which trees are intercropped with annual crops or with grasslands, have the capacity to store more carbon in the soil in comparison to reference systems [1, 2, 3]. The residence time of the carbon additionally stored in the soil is critical in the perspective of mitigating greenhouse gas emissions. To our knowledge, the temporal stability this carbon has not been assessed yet. To do so, we used a long term agroforestry experiment located in southeast France, where hybrid walnuts have been planted 18 years ago, with a density of 110 trees ha-1 and are intercropped with durum wheat. The soil is a silty and carbonated deep alluvial Fluvisol. Soil OC stocks have been measured on this site and we sampled the tree row, the inter-row and the reference plot down to 180 cm. Samples have been incubated in the laboratory at pF 2.5. The evolved CO2 was monitored as well as its δ13C. The measurements were performed in order to quantify the contribution of soil organic matter and carbonates to the evolved CO2. We found that carbonates made an important contribution to the evolved CO2, with up to 70% of evolved CO2 presumably originating from the carbonates. There was no different of SOC mineralization rates between the tree row, inter-row and control plot except in the 0-10 cm layer where it was larger in the former. This could be explained by the abundance of SOC in this layer of tree rows corresponding to particulate organic matter. The mineralization rates of SOC decreased with depth, showing the increased stability of SOC in the subsoil. We found no evidence of increased stability of the organic carbon stored in agroforestry plots. Most of the additionally stored organic C occurs in the surface layer and is labile (particulate organic matter). Below 10 cm rates of mineralization as measured in vitro are similar, but more SOC is present in the agroforestry plot, in particular in the tree row. This study also shows the importance of accounting for inorganic carbon when measuring mineralization rates of organic matter in calcareous soils.

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O-4a.08

Which is the best method to isolate soil organic carbon fractions with distinct turnover times?

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A myriad of methods to fractionate soil organic carbon (SOC) exists, which have been developed based on different research questions and views of SOC stabilization mechanisms. A major goal of SOC fractionation is to separate the bulk SOC into fractions having discrete turnover times. The lack of a comprehensive method comparison impedes the choice for a method. For an international methods comparison study (SOMfrac) we used soils from three experimental sites with long-term C3-C4 vegetation changes (22, 22 and 36 years ago) and tested 21 different SOC fractionation methods. Using the natural abundance of δ13C, we were able to track the enrichment of C4-derived carbon in different SOC fractions as an indirect measure for turnover time. The methods that apply a combination of physical (density, size) and chemical (oxidation, extraction) were most effective to obtain fractions with a wide range of turnover times. Coarse light fraction SOC and oxidation resistant SOC were the most and least C4-carbon enriched fractions, respectively. Surprisingly, even after 36 years of C4-plant cultivation (Maize and Miscanthus), no method was able to isolate a fraction were the C3-carbon was completely replaced by C4-carbon. This hampers the direct link between any fractions of SOC and the most active and labile pool in SOC models. Particles with a density of >2.8 g cm^3 showed similarly low C4-carbon enrichment as oxidation resistant SOC, indicating the importance of metal-oxides for SOC stabilization. Particle size fractionation significantly outperformed aggregate size fractionation because of the fact that larger aggregates contain smaller ones. Using further quality criteria such as redundancy in turnover time, recovery and reproducibility, an evaluation scheme was established to identify and evaluate the strengths and weaknesses of the 21 different methods.

O-4b.03

The energetic and chemical fingerprints of persistent soil organic carbon

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The absence of convincing physical or chemical procedures to characterize or isolate relatively labile versus persistent soil organic carbon (SOC) pools makes the study of persistent SOC difficult. Long-term bare fallow (BF) experiments, in which C inputs have been stopped for decades, provide a unique opportunity to study persistent SOC without the inherent artefacts induced by extraction procedures, the hypothesis being that SOC is gradually enriched in persistent C with time as labile components decompose. We determined the evolution of thermal and chemical characteristics of bulk SOC in five long-term BF experiments across Europe (Askov, Grignon, Rothamsted, Ultuna and Versailles), using a multi-technique approach involving Rock-Eval pyrolysis (RE), thermogravimetry and differential scanning calorimetry (TG-DSC), Near Edge X-Ray Absorption Fine Structure (NEXAFS) and pyrolysis gas chromatography-mass spectrometry (TMAH-Py-GC-MS). Results of RE and TG analyses showed that the temperature needed to combust the SOC increased with BF duration at all sites. Conversely, SOC energy density (in mJ mg-1 C) measured by DSC decreased with BF duration. RE results showed that hydrogen index (HI) tended to decrease with BF duration whereas the oxygen index (OI) did not show consistent trends across sites. NEXAFS signals presented little differences and were dominated by carboxyl peak. TMAH-Py-GC-MS results showed a strong relative decrease in lignin-derived compounds with BF duration and a small decline in cutin and suberin-derived compounds. Conversely, the relative intensity of alkanes increased with bare fallow duration. Our results showed that in spite of the heterogeneity of the soils at the 5 long-term BF sites, SOC that has persisted in soils for several decades have similar and defined thermal and energetic properties: persistent SOC burns at higher temperature and its combustion generates less energy. Persistent SOC in the studied temperate soils also shares some chemical properties: it has a lower HI values and is depleted in lignin-derived compounds. The increased burning temperature and lower energy density of persistent SOC suggest that SOC stability may be a function of the high energy cost and low energy gain from decomposition of this material.

O-5b.10

Does pore scale biogeography exist in different soil types?

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Microbial activity is largely controlled by the abiotic conditions prevailing in their habitats, which are very heterogeneous at the microscopic scale. A few studies have demonstrated a microbial biogeography at the pore scale. Different regions in the soil pore network can be considered to be different microbial habitats and these different regions have been shown to be well correlated with organic carbon mineralization rates. We aimed to test whether such a functional biogeography exists for different soil types and whether it is consistent across soils. We selected six topsoils with contrasted texture, soil organic matter content and pH (2 cambisols, 3 luvisols and 1 podzol under different managements). We added a 13C labelled, easily mineralisable organic substrate, pyruvate, to soil samples previously equilibrated at different matric potentials, in order to place the substrate preferentially in soil pores with neck diameters of 3 to 10 µm or 30 to 10µm, according to the Jurin-Laplace law. The soil samples were then incubated at pF 1.5 for 3 weeks and CO2 and 13C-CO2 were monitored. At the end of incubation, total and 13C-PLFA were extracted and analysed. Basal mineralisation, expressed as % total organic C was affected by soil type, mainly related soil pH and the quality[NN1] of the organic matter. The 6 soils exhibited contrasted microbial community composition, as shown by their PLFA profiles. The addition of pyruvate did not induce any priming effect in soils, except in the long term bare fallow soil, where the mineralization of SOM was presumably limited by energy. In the long term bare fallow soil, pyruvate mineralization was the same whatever the region it was placed in, suggesting other controls of its mineralization than the characteristics of pore scale habitats. In four soils out of six, the mineralization of pyruvate was more rapid when it was initially placed in large pores (30 to 100µm) than in small pores (3 to 10 µm), suggesting that pore scale biogeography may be a general feature in soils and that coarser pores are more favourable habitats for soil organic matter mineralization.

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Promoting carbon sequestration in soils: The 4 per 1000 initiative

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The "4‰" Initiative was launched at the COP21 as part of the Lima-Paris Action Agenda. It aims to improve the organic matter content of soils and promote soil organic carbon (SOC) sequestration to increase soil fertility and thereby contribute to food security, to foster adaptation to climate change and contribute to mitigating climate change. The initiative focuses primarily on agricultural soils, because of their frequent poor soil organic carbon content and degradation and of their crucial role in food provision but also considers forest soils and the preservation of existing SOC stocks. The objectives of the initiative are:

(i) to promote research on the knowledge needed for the initiative (mechanisms and potential of organic C sequestration in soils; SOC sequestering management agricultural and forestry practices; adoption and transition to these practices; monitoring SOC stocks) and to
(ii) to foster initiatives, by a variety of actors, to better manage SOC in the field via agricultural practices.
The governance of the "4‰" Initiative is organised into three bodies, which will interact closely with each other: the consortium of all members, who elect the president and vice president of the initiative, the forum of partners and the scientific and technical committee (STC). The work of all these bodies is facilitated by the executive secretary.

The STC has the mission to support SOC sequestration programs initiated by a wide variety of actors by setting reference criteria for the evaluation of SOC management projects and actions. The committee will give advice on these actions and formulate proposals for the orientations of international scientific research and cooperation programs. The advice given by the STC is founded on the principles and goals of the Initiative and coherent with the Sustainable Development Goals. This presentation will present the on-going work of the STC on the sustainable SOC sequestration indicators. The challenge is to identify easily utilizable indicators relative to SOC storage itself, but also to mitigation of GHG emissions, improved productivity and food security, better adaptation to climate change, but also relative to other impacts of SOC sequestration strategies (on water quality or land tenure for example).