SoilCET 2024

ABSTRACT BOOK

SoilCET 2024 - PROGRAMME

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Wednesday January 24 (1 p.m – 6.40 p.m)

1.00 p.m – 2 p.m *Registration in front of amphitheater Dhalias (-1 floor) & Welcome coffee*

2.00 p.m – 2.15 p.m Opening address in amphitheater Dhalias (-1 floor)

2.15 p.m – 2.45 p.m Inaugural conference
Cornelia Rumpel

2.45 p.m – 3.00 p.m Applications of the “4 per 1000” Initiative
Paul Luu

SESSION 1: QUANTIFICATION OF ORGANIC CARBON AND CHARACTERISATION OF SOIL ORGANIC MATTER AT PLOT AND REGIONAL SCALES

Chairpersons: Emmanuelle Vaudour & Sergio Saia

3.00 p.m – 3.40 p.m Keynote speaker: **Tiphaine Chevallier**
QUANTIFICATION AND CHARACTERISATION OF SOIL CARBON AT DIFFERENT SCALES

3.40 p.m – 4.00 p.m SENTINEL-2/1 BARE SOIL TEMPORAL MOSAICS OF 6-YEAR PERIODS FOR SOIL ORGANIC CARBON CONTENT MAPPING IN LA BEAUCE, CENTRAL FRANCE
Emmanuelle Vaudour

4.00 p.m – 4.20 p.m APPLICATIONS OF INFRARED SPECTROSCOPY TO QUANTIFY AND CHARACTERIZE SOIL ORGANIC CARBON
Aurélie Cambou

4.20 p.m – 4.25 p.m PRESENTATION OF INTERNATIONAL RESEARCH CONSORTIUM ORCASA
Mathieu Noguès

→ *4.45 p.m – 4.55 p.m: Presentation of International Research Consortium ORCaSa (in front of Poster*

4.25 p.m – 5.20 p.m ***Coffee Break***
Stand visit
Poster session

Presented by	Poster title
Maria ROMERO-SARMIENTO	Rock-Eval® device for characterization of environmental samples: methods, insights, and applications.
Adrien WATTRIPONT	Carbon Farming practices verified by Rock-Eval soil analysis
Lucas POULLARD	Effects of mechanical site preparation techniques in forest plantation context on the soil organic carbon stocks and on the priming effect process.
Stéphanie OUVRARD	Assessment of C storage of a Technosol under short rotation coppice management
Brieuc HARDY	The SOC:clay ratio – a measure of the organic carbon saturation of soil indicative of its potential structural stability

Imran Ahammad SIDDIQUE	Assessing the carbon fluxes in perennial and annual cropping systems using both automatic and manual chamber methods

5.20 p.m – 5.40 p.m PROPOSITION FOR A METHODOLOGICAL FRAMEWORK AND PROTOTYPE MRV TOOL FOR CROPLAND C STOCK CHANGE ASSESSMENT AT HIGH RESOLUTION OVER LARGE REGIONS
Eric Ceschia

5.40 p.m – 6.00 p.m CHANGES IN SOIL ORGANIC CARBON CONTENT UNDER ANNUAL AND PERENNIAL CROPS, AND RELATED AGRICULTURAL PRACTICES AS OBSERVED FROM A LARGE SCALE ON-FARM STUDY IN SWITZERLAND
Pascal Boivin

6.00 p.m – 6.20 p.m ADJUSTMENTS OF THE ROCK-EVAL® THERMAL ANALYSIS FOR SOC AND SIC QUANTIFICATIONS
Joséphine Hazera

6.20 p.m – 6.40 p.m QUANTIFICATION OF BIOCHAR IN ARABLE LAND: A NEW APPROACH WITH ROCK-EVAL® THERMAL ANALYSIS
Marie-Liesse Aubertin

Thursday January 25 (8.30 a.m – 5.40 p.m) – Cocktail Reception (from 19p.m)

8.30 a.m – 9 a.m ***Welcome coffee***

SESSION 2: STABILISATION OF SOIL ORGANIC MATTER: A CENTRAL PROCESS IN C-STORING AGRICULTURAL PRACTICES

Chairpersons: Isabelle Basile-Doelsch & Patricia Garnier

9.00 a.m – 9.40 a.m Keynote speaker: **Claire Chenu**
STORING ADDITIONAL CARBON IN SOIL: DIFFERENT PRACTICES, DIFFERENT STABILITIES OF THE ORGANIC MATTER?

9.40 a.m – 10.00 a.m ABOUT SOME CURRENT CONTROVERSIES ON MECHANISMS CONTROLLING CARBON STORAGE IN SOILS
Delphine Derrien

10 a.m – 10.20 a.m SATURATION OF CLAY SURFACES BY ORGANIC MATTER: CONSEQUENCES ON PHYSICAL, CHEMICAL AND MICROBIOLOGICAL PROPERTIES
Irina Mikajlo

10.20 a.m – 10.25 a.m EUROPEAN JOINT PROJECT SOIL
Claire Chenu
→ *10:50 a.m -11:00 a.m : Presentation of European Joint Project Soil (in front of Poster)*

10.25 a.m – 11.20 a.m ☕ ***Coffee Break***
🔬 ***Stand visit***
📷 **Group Photo**
📈 ***Poster session***

Presented by	Poster title
Clémentine CHIROL	Effect of agricultural management practices on soil structural stability and organic matter deprotection during drying-rewetting cycles
Brahima K. SILUE	Dynamics of organic carbon storage in cacao-based agroforestry system soils in Divo.
Chiara POESIO	Influence of different agricultural managements on soil organic matter distribution and stability in topsoil and subsoil.
Nick QUIST	Changes in chemical composition of humic substances during microbial composting and Agaricus bisporus mycelial growth
Robin BÉGHIN-TANNEAU	Characterization by thermal analysis of soil organic matter storage induced by organic amendments
Amicie DELAHAIE	Investigating the complementarity of thermal and physical soil organic carbon fractions in mainland France
Inass ZAYANI	Soil Organic Carbon Storage in Moroccan Agroforestry Olive Orchards

11.20 a.m – 11.40 a.m ORGANIC MATTER QUALITY IN ARABLE LAND AS INFLUENCE BY CLAY CONTENT AND CROPPING SYSTEM
Cédric Deluz

11.40 a.m – 12 p.m THERMO-CHEMICAL CHARACTERISATION OF ORGANIC MATTER IN AGRICULTURAL SOILS SUBJECTED TO LONG-TERM CHEMICAL OR ORGANIC FERTILISATION
Thomas Lerch

12 p.m – 12.20 p.m ORGANIC MATTER STABILIZATION IN CONSTRUCTED SOILS MANUFACTURED WITH CLAY-RICH WASTE
Samuel Coussy

12.20 p.m – 12.40 p.m WHOLE SOIL WARMING PROMOTES SUBSOIL CARBON GAIN DEPENDING ON LAND MANAGEMENT PRACTICES IN TEMPERATE CLIMATE MD.
Zulfikar KHAN

12.40 p.m – 2 p.m 🍽 ***Lunch Break at Sequoia building (3rd floor)***

SESSION 3: THE ROLE OF BIODIVERSITY IN SOIL ORGANIC MATTER STABILISATION AND CARBON STORAGE

Chairpersons: Delphine Derrien & Marie-France Dignac

2.00 p.m – 2.40 p.m Keynote speaker: **Petr Baldrian**
MICROBIOME OF FOREST SOILS: BIODIVERSITY, FUNCTION AND RESPONSES TO GLOBAL CHANGE

2.40 p.m – 3 p.m — THE ROLE OF SOIL FAUNA ON SOIL ORGANIC MATTER STORAGE DEPENDS ON ORGANIC MATTER INTERACTION WITH MINERAL MATRIX BUT NOT ONLY ON THAT.
Jan Frouz

3 p.m – 3.20 p.m — SOIL MACRO INVERTEBRATES ENHANCE C STORAGE IN TROPICAL SOILS FOLLOWING APPLICATION OF THE FBO TECHNOLOGY
José H. R. ARAUJO Araujo

3.20 p.m – 3.25 p.m — THE FRENCH PROGRAM FAIRCARBON
Patricia GARNIER
→ 3.50 p.m – 4 p.m : Presentation of the French Program FAIRCARBON (in front of Poster)

3.25 p.m – 4.20 p.m — ***Coffee Break***
Stand visit
Poster session

Presented by	Poster title
Abdelrahman ALAHMAD	Unveiling the Potential of Soil Prebiotics: Indigenous Microbial Recruitment for Enhanced Soil Health, Plant Growth, and Carbon Sequestration
Marie-Louise SPALINGER	The role of plant functional group diversity on soil carbon cycling processes in a simple model soil
Senta HEISS-BLANQUET	Impact of the molecular structure and microbial community features on the stability of organic components in soil
Nicolas PANNACCI	Characterizing stability and dynamics of organic matter in worm compost using Rock-Eval® analysis - preliminary results
Pascal BOIVIN	Monitoring carbon stocks in arable land: sources of errors, improvement of the one-layer equivalent soil mass method and minimum detectable change
Sergio SAIA	Role of time and cover crop on soil chemico-physical traits in an olive orchard in a semiarid area

Chairpersons: Delphine Derrien & Priscia Oliva

4.20 p.m – 4.40 p.m — INFLUENCE OF INTRA- AND INTER-SPECIFIC PLANT BIODIVERSITY ON SOIL FUNCTIONING: SOIL RESPONSE UNDER THE USE OF EVOLUTIONARY POPULATIONS IN A ROTATION SYSTEM
Charlotte Védère

4.40 p.m – 5 p.m — RHIZODEPOSITION PLANT-PROPERTIES AND PREVIOUS LAND-USE CONTROL BOTH MICROBIAL COMMUNITIES AND SOIL CARBON ADDITIONNAL STORAGE
Sarah Wagon

5 p.m – 5.20 p.m — FOLLOW-UP (STABLE ISOTOPE) OF RHIZODEPOSITION AND LITTER IN SOIL MESOFAUNA UNDER 15 GRASSLAND SPECIES WITH CONTRASTING STRATEGIES
Chloé Folacher

5.20 p.m – 5.40 p.m — IMPROVING THE SIMULATION OF CO2 FLUXES INTEGRATING MICROBIAL BIODIVERSITY INTO A SIMPLE SOIL ORGANIC CARBON MODEL
Elisa Bruni

5.40 p.m – 6.40 p.m ***Free Time***

6.40 p.m – 7 p.m Guided walk from IFPEN to the Domaine de Vert-Mont

7 p.m – 10 p.m 🍸 **Cocktail Reception *at the Domaine of Vert-Mont***
Venue: 3 avenue Tuck Stell - Rueil-Malmaison

Friday January 26 (8.30 a.m – 2 p.m)

8.30 a.m – 8.45 a.m ***Welcome coffee***

SESSION 4 : MICROBIOLOGICAL, GEOCHEMICAL AND MATTER TRANSFER INTERACTIONS: AN INTEGRATED APPROACH

Chairpersons: Luiz Domeignoz Horta and Katell Quénéa

8.45 a.m - 9.25 a.m Keynote speaker: **Wilfred Otten**
PHYSICAL PROTECTION OF ORGANIC MATTER: A BIOPHYSICAL MODEL

9.25 a.m – 9.45 a.m MODELLING SOIL MOISTURE CONTROL ON SOIL ORGANIC CARBON DECOMPOSITION AND LAND-ATMOSPHERE CARBON FLUXES IN A GLOBAL SCALE ECOSYSTEM MODEL
Elodie Salmon

9.45 a.m – 10.05 a.m PLANT DIVERSITY DRIVES POSITIVE MICROBIAL ASSOCIATIONS IN ROOTS ENHANCING CARBON USE EFFICIENCY IN AGRICULTURAL SOILS
Luiz Alberto Domeignoz-Horta

10.05 a.m – 10.25 a.m PSEUDOMONAS BRASSICACEARUM MINERAL WEATHERING ACTIVITY IS LINKED TO IRON HOMEOSTASIS AND CAN PARTICIPATE TO SOIL ORGANIC CARBON STABILIZATION
Tom Girard

10.25 a.m – 10.30 a.m THE SHARInG-MeD PROJECT: THE TRADE-OFF BETWEEN SOIL HEALTH, LAND USE, SOIL AND CROP MANAGEMENT FROM AND AGRONOMIC, ECONOMIC AND ENVIRONMENTAL POINT OF VIEW IN THE MEDITERRANEAN AREA
→ 10.50 a.m – 11 a.m : Presentation of the PRIMA SHARInG-MeD Project (in front of Poster)

10.30 a.m – 11.20 a.m ☕ ***Coffee Break***
🔬 ***Stand visit***
📈 ***Poster session***

Presented by	Poster title
Elisa PELLEGRINI	Species richness of tree plantations affects pathways of carbon incorporation into soil organic matter
Carlos Rufino JUAREZ-DE-	Understanding the gas exchange mechanisms between permafrost soils and the atmosphere in Daring

LEON	Lake (Canada): Implications to the climate change.
Daria DERBILOVA	Organic matter in the archaeological agricultural soils of Gabon
Imran Ahammad SIDDIQUE	Soil organic carbon stock change following perennialization: A meta-analysis
Perrine COLOGON	Characterization of organic matter in peat samples with Py-GC/MS: from methodological challenges to identification of relevant molecular indicators
Olivier TAUGOURDEAU	Variability and drivers of sediments organic carbon stock in the Arcachon Bay (France)
Amal DILMI	Estimation of soil organic carbon contents in subhumid zone under the Mediterranean Bainem forest

11.20 a.m – 11.40 a.m LAND USE DETERMINES THE COMPOSITION AND STABILITY OF ORGANIC CARBON IN EARTHWORM CASTS UNDER TROPICAL CONDITIONS
Chao Song

11.40 a.m – 12.00 p.m STORAGE OF DEEP CARBON IN THE BERAMBADI WATERSHED (INDIA): A COMPARATIVE STUDY BETWEEN AGROFORESTRY AND IRRIGATED AGRICULTURE
Zoé Favaro

12.00 p.m – 12.10 p.m Young researcher award for the best symposium poster

12.10 p.m – 12.30 p.m **Conclusion**
Key witnesses: Sophie Violette, Sophie Cornu, Abad Chabbi

12.10 p.m – 12.30 p.m **End of conference – Organising Committee**

12.40 p.m – 2 p.m ***Lunch buffet at Sequoia building (3rd floor)***
(take away available in front of amphitheater Dahlias)

Session 1

QUANTIFICATION OF ORGANIC CARBON AND CHARACTERISATION OF SOIL ORGANIC MATTER AT PLOT AND REGIONAL SCALES

Quantification and characterisation of soil carbon at different scales.

Tiphaine CHEVALLIER

Eco&Sols, IRD, CIRAD, INRAE, L'institut Agro, University of Montpellier, Montpellier, France

Soil carbon (C), essentially soil organic carbon (SOC), is a common indicator to monitor soil health. Soil ecosystem services (e.g. food production, water retention and filtration, biodiversity habitats) are mainly supported by soil organic matter stocks and fluxes. Soils have also a potential to mitigate climate change by storing C. However, measuring carbon stocks and evaluating its evolution with time needs different assumptions to be representative to a geographical area and eventually to a specific soil function. Soil C is found in several forms (e.g. organic, microbial or plant derived SOC, inorganic C) and reactivity (e.g. SOC labile and SOC resistant). These different pools of C with different turn over affect and are indicators of different soil functions. For instance, the labile SOC stocks are indicators of plant nutrients recycling whereas resistant SOC stocks are indicators of the soil climate change mitigation role. There is thus a need to be able to quantify and characterise the soil carbon at different scales.

Global C stocks, C fluxes and C pools are directly measured or indirectly measured with different technics. Various extrapolation models, extrapolation in time, in space, or even both, are calibrated and validated on field measured data. National and international efforts are made to harmonize the soil analysis and to develop large soil health monitoring. However, in addition to logistical headwinds (field/site accessibility, equipment accessibility and maintenance, technical human resources, management of soil sample archives), there are still some methodological challenges to produce satisfactory soil C data and soil C pools in every kind of soil types. Calcareous soil are especially less studied. Characterizing soil carbon stocks, pools and fluxes are especially difficult in these soils, although 30% of soils are calcareous. Support technical capacity building and methodological research in C measurements to supply quality data are still needed. Especially, there is an urgent need to fix and harmonize methodological technics to quantify and characterize soil carbon in calcareous soils.

Sentinel-2/1 bare soil temporal mosaics of 6-year periods for Soil Organic Carbon Content mapping in La Beauce, Central France

Diego URBINA-SALAZAR [1],[2], Emmanuelle VAUDOUR [1], Anne C. RICHER-DE-FORGES [2], Songchao CHEN [3,4], Guillaume MARTELET [5], Nicolas BAGHDADI [6], Dominique ARROUAYS [2]

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[6] TETIS, Univ. Montpellier, INRAE, CIRAD, AgroparisTech, France

Abstract:
Satellite-based soil organic carbon content (SOC) mapping over wide regions is generally hampered by the low soil sampling density and the diversity of soil sampling periods. Some unfavorable topsoil conditions, such as high moisture, rugosity, the presence of crop residues, the limited amplitude of SOC values and the limited area of bare soil when a single image is used, are also among the influencing factors. To generate a reliable SOC map, this study addresses the use of Sentinel-2 (S2) temporal mosaics of bare soil (S2Bsoil) over 6 years jointly with soil moisture products (SMPs) derived from Sentinel 1 and 2 images, SOC measurement data and other environmental covariates derived from digital elevation models, lithology maps and airborne gamma-ray data. In this study (Urbina-Salazar et al., 2023 doi.org/10.3390/ rs15092410), we explore (i) the dates and periods that are preferable to construct temporal mosaics of bare soils while accounting for soil moisture and soil management; (ii) which set of covariates is more relevant to explain the SOC variability. From four sets of covariates (Figure 1, table 1), the best contributing set was selected, and the median SOC content along with uncertainty at 90% prediction intervals were mapped at a 25-m resolution from quantile regression forest models. The accuracy of predictions was assessed by 10-fold cross-validation, repeated five times. The models using all the covariates had the best model performance. Airborne gamma-ray thorium, slope and S2 bands (e.g., bands 6, 7, 8, 8a) and indices (e.g., calcareous sedimentary rocks, “calcl”) from the “late winter–spring” time series were the most important covariates in this model. Our results also indicated the important role of neighboring topographic distances and oblique geographic coordinates between remote sensing data and parent material. These data contributed not only to optimizing SOC mapping performance but also provided information related to long-range gradients of SOC spatial variability, which makes sense from a pedological point of view.

This research was supported by the POLYPHEME project through the TOSCA program of the Centre national d'études spatiales (CNES), STEROPES project of the EJP-SOIL Horizon H2020 and the MELICERTES project of the French National Research Agency (France2030, PEPR “agroécologie et numérique”).

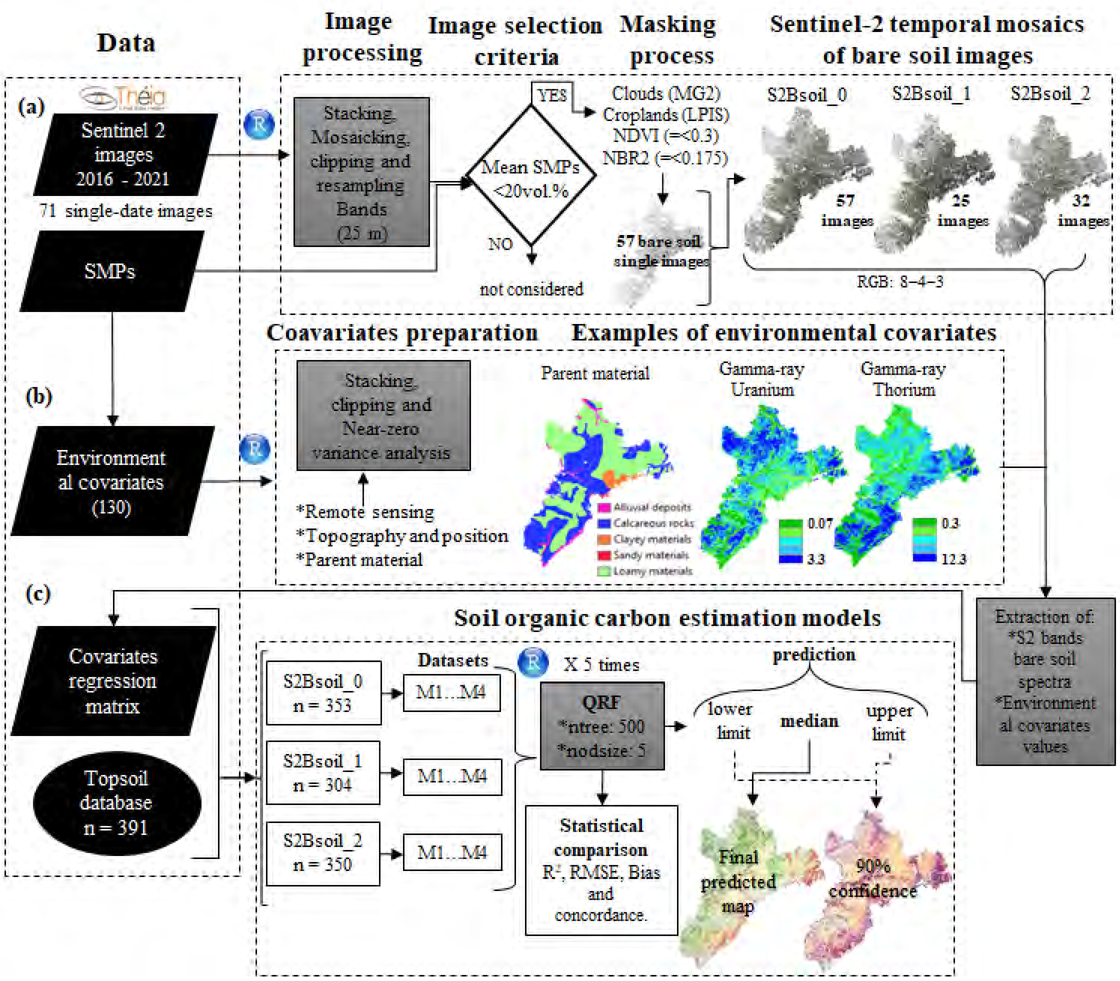


Figure 1. Flowchart methodology. Sentinel-2 temporal mosaics of bare soil (S2Bsoil) over 6 years: S2Bsoil_0, 57 images used; S2Bsoil_1, 25 images between February and May; S2Bsoil_2, 32 images between July and November. Sets of covariates: M1, the 10 S2Bsoil bands; M2, the 10 S2Bsoil bands plus spectral indices were considered (24 covariates); M3, the same covariates used in (M2) plus soil moisture were used (25 covariates); M4, all covariates used in (M1 to M3) plus covariates of topography and position and parent material (85 covariates).

Table 1. Model performance of a Quantile Random Forest to predict soil organic carbon by mosaics of bare soil over a 6-year period

S2Bsoil	Modeling dataset	R^2	RMSE (g.kg^{-1})	Bias	Concordance
S2Bsoil_0	M1	0.18	3.00	−0.33	0.32
	M2	0.19	2.98	−0.31	0.33
	M3	0.15	2.98	−0.30	0.29
	M4	0.26	2.75	−0.20	0.40
S2Bsoil_1	M1	0.19	2.97	−0.32	0.35
	M2	0.22	2.90	−0.30	0.35
	M3	0.22	2.79	−0.28	0.34
	M4	0.33	2.59	−0.22	0.42
S2Bsoil_2	M1	0.11	3.17	−0.35	0.25
	M2	0.11	3.14	−0.30	0.24
	M3	0.12	3.00	−0.29	0.25
	M4	0.27	2.71	−0.21	0.39

R^2, coefficient of determination; RMSE, root mean square error.

Applications of infrared spectroscopy to quantify and characterize soil organic carbon

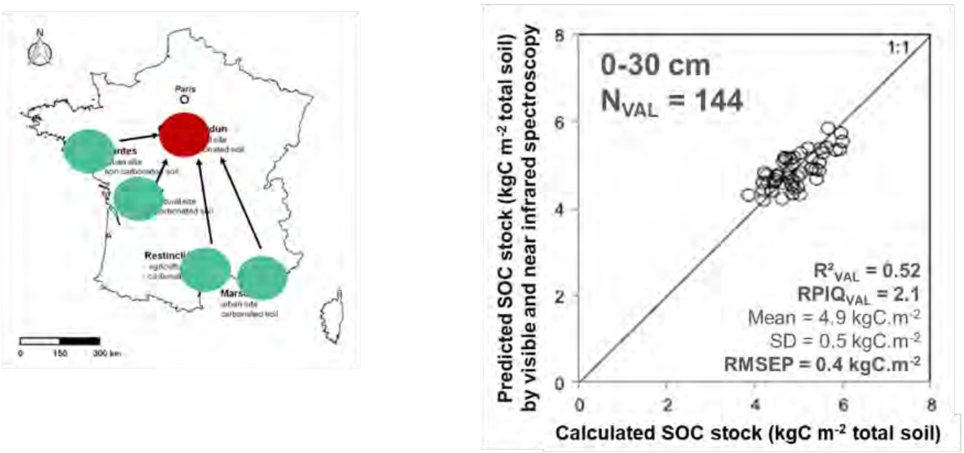
Aurélie CAMBOU, Bernard G. BARTHÈS, Tiphaine CHEVALLIER

Eco&Sols, Université de Montpellier, Cirad, Inrae, IRD, Institut Agro, 34060 Montpellier, France

Abstract:
Soil organic carbon (SOC) contributes to the maintenance of soil physical, chemical, and biological functions. However, the conventional methods for (i) quantifying SOC stock (in kgC m^{-2} for a given soil layer), which is the product of SOC concentration (gC kg^{-1}) by volumetric mass (kg dm^{-3}), and (ii) identifying SOC fractions, which provide information about SOC dynamics and stability, are time-consuming and tedious.
The use of infrared (IR) spectroscopy has been developed to quantify soil properties (Janik et al., 1998, *doi: 10.1071/EA97144*; Viscarra Rossel et al., 2006, *doi: 10.1016/j.geoderma.2005.03.007*; Stenberg et al., 2010, *doi: 10.1016/S0065-2113(10)07005-7*). This is a rapid, non-destructive and reproducible approach, that can be used in both laboratory and the field, with low unit cost, and no consumables or waste. Moreover, various properties can be determined from a single spectrum. Two spectral domains are often used: the near IR (800-2500 nm) and the mid-IR (2500-25,000 nm). Most current uses of IR spectroscopy are based on calibrations built by multivariate regressions on calibration samples characterized both conventionally (e.g., by dry combustion for SOC) and spectrally. These calibrations can then be applied to new samples to predict the variable of interest (e.g., SOC) using their spectrum. Thus, the variable of interest is not measured by IR spectroscopy but predicted, with an associated uncertainty.
Many works demonstrated that IR spectroscopy allows accurate prediction of SOC concentration (gC kg^{-1}), at different scales (plot, region, country). Better predictions with mid- than near IR have often been reported for soil samples from temperate regions, finely ground at 0.2 mm. On the contrary, better predictions with near IR have often been reported for tropical and/or 2-mm sieved soil samples. Current development of large calibration databases for SOC concentration, and progress in spectral data analysis pave the way for wide use of IR spectroscopy, which should help solving the SOC data crisis. Recent works also showed an interest of IR spectroscopy for directly predicting SOC stocks, without having to determine SOC concentration and volumetric mass (except for calibration), but corresponding calibration databases are still limited to date. Predictions of SOC stock are more accurate in general when using spectra of dry soil < 2 mm than using field spectra, except when coarse particle content (> 2 mm) is high and varies between samples. Furthermore, several studies showed the IR spectrum of bulk soil could be used for predicting SOC distribution among its fractions, for instance particle size fractions, and corresponding calibration databases are being developed. Thus, IR spectroscopy facilitates SOC characterization, and increases the value of conventional analyses carried out on some samples by using them for predictions on other samples.
In short, IR spectroscopy has strong potential for supporting better SOC monitoring. This communication proposes an overview on the benefits of IR spectroscopy for rapid, low-cost quantification of SOC in terms of concentration and stock, and of its particle size fractions.

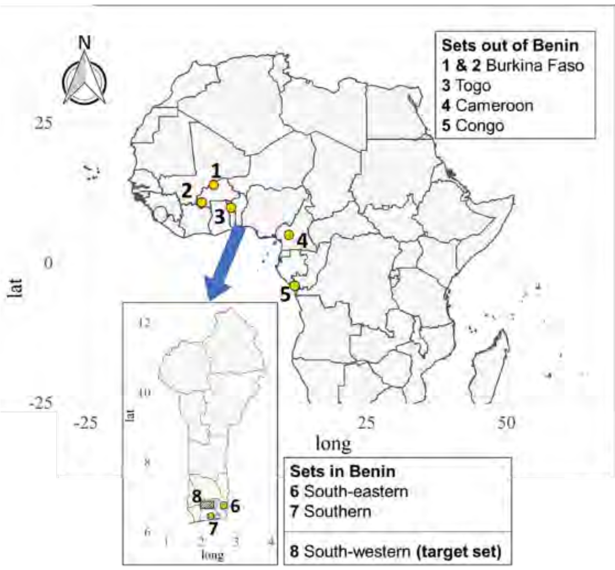
Annex

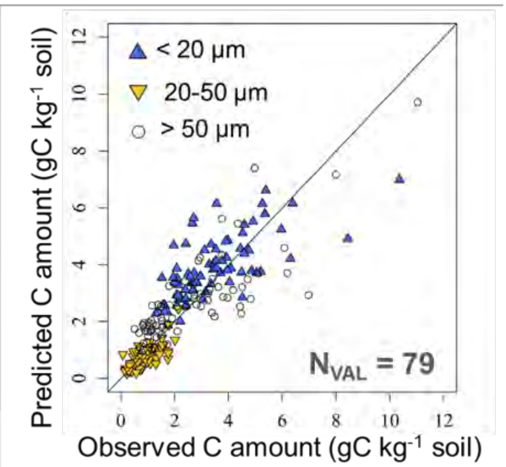
Prediction of SOC stock (kgC m⁻²) in French sites using near IR spectra of soil < 2 mm (four calibration sites in green, one validation site in red)



Cambou, A., Allory, V., Cardinael, R., Carvalho Vieira, L., Barthès, B.G., 2021. Comparison of soil organic carbon stocks predicted using visible and near infrared reflectance (VNIR) spectra acquired in situ vs. on sieved dried samples: Synthesis of different studies. Soil Security 5, 100024. DOI: 10.1016/j.soisec.2021.100024

Prediction of SOC particle size distribution in west-African sites using near IR spectra of bulk soil (seven calibration sites in yellow, one validation site in green)





RMSEP (< 20 µm) = 1.2 gC kg^{-1} soil < 2 mm
RMSEP (20-50 µm) = 0.3 gC kg^{-1} soil < 2 mm
RMSEP (> 50 µm) = 1.1 gC kg^{-1} soil < 2 mm

Cambou A., Houssoukpèvi I.A., Chevallier T., Moulin P., Rakotondrazafy N.M., Fonkeng E.E., Harmand J.-M., Aholoukpè H.N.S., Amadji G.L., Tabi F.O., Chapuis-Lardy L., Barthès B.G., submitted. Quantification of soil organic carbon in particle size fractions using a near infrared spectral library in West Africa.

Soil Carbon International Research Consortium

Mathieu Nogues

INRAE

Join the soil carbon community!
The Soil Carbon International Research Consortium (IRC) will be launched in a few weeks, in the framework of ORCaSa - a three-year Horizon Europe initiative -, and its 5 regional nodes. It will support the Paris Agreement and the SDGs. Hand in hand with the 4p1000 Initiative, the Soil Carbon IRC will cover all soils : agriculture lands, forests, pastures, wetlands, urban areas, etc. Whether you are a university, research organisation, national or international initiative or programme, living lab, R&D agency, foundation, bank, private company, start-up, policymaker, agriculture expert, or NGOs working with food, climate and environmental topics, you can already join the Soil Carbon IRC ! Depending on your expertise and type of involvement, you will be part of one of the three colleges (researchers, funders, and users), and included in the regional node corresponding to your location.

Targeted services delivered by the Soil Carbon IRC:

1. Harmonisation MRV framework

You can be part of an international community truly committed to raise awareness and develop scientific knowledge on how to measure, report and verify soil carbon stock changes by contributing to an internationally harmonised Monitoring, Reporting, and Verification (MRV) framework

2. Open access knowledge platform

You can access and contribute to a knowledge platform driving you to :- scientific evidence through meta-analysis and reviews- description of best practices from verified sources- interactive mapping of data (for instance, easy visualisation of carbon stock and its evolution) - initiatives, projects, and a large network of stakeholders.

3. Research alignment and calls

You can contribute to an aligned Strategic Research and Innovation Agenda (SRIA) that will consider all types of land use in each region to ensure that soils play a role in soil health and innovation for climate change mitigation and adaptation. In addition, you will access to funds designed to facilitate international collaboration between projects. The Soil Carbon IRC will propose calls dedicated to the implementation of the SRIA and negotiate them with international funders.

Proposition for a methodological framework and prototype MRV tool for cropland C stock change assessment at high resolution over large regions

Eric Ceschia[1,4], Ahmad Al Bitar[1], Taeken Wijmer[1], Ludovic Arnaud[1], Veronica Antonenko[1], Andrea Geraud[1,2], Ainhoa Ihasusta[1], Rémy Fieuzal[1], Gerard B.M. Heuvelink[3], Niels H. Batjes[3], Fenny van Egmond[3], Suzanne Reynders[4]

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[4] INRAE, 147 Rue de l'Université, 75007 Paris

Abstract:
Increasing soil organic carbon (SOC) stocks is a well-identified climate change mitigation solution. However, accurate and extensive estimation of cropland SOC stock changes for National Inventories, for the Common Agricultural Policy or for the voluntary carbon market with in-situ measurements exclusively would be too costly. For this reason, soil or coupled plant/soil models are often used to quantify SOC stock changes but these models make many simplifying assumptions and lack accuracy when assessing the effect of the spatial variability in biomass production on SOC stock changes. This effect can be substantial when considering for instance cover crops. Therefore, Paustian et al. (2019, DOI:10.1080/17583004.2019.1633231) and Smith et al. (2020, DOI: 10.1111/gcb.14815) have proposed theoretical frameworks for the Monitoring, Reporting and Verification (MRV) of agricultural SOC stock changes relying on the combination of high-resolution remote sensing data, field information, and physical models. However, there is still no clear methodological framework nor set of tools that would allow to consistently monitor SOC stock changes in those different contexts following those theoretical frameworks.
For this reason, the ORCaSa project has proposed a methodological framework for MRV and a prototype of Operational Processing Chain (OPC) for cropland. We present here both the methodological framework and the AgriCarbon-EO OPC that provides the yield, biomass, water and carbon budget components of agricultural fields at 10m resolution and at regional scale. The OPC has been optimized to assimilate high resolution optical remote sensing data (Sentinel-2 and Landsat-8) into a radiative transfer model and a coupled crop/soil model. First, the application of a spatial Bayesian retrieval approach to the PROSAIL radiative transfer model provides Leaf Area Index (LAI) with its associated uncertainty for each date of satellite acquisition in clear conditions. Second, LAI is assimilated into the SAFYE-CO2 crop model using a temporal Bayesian retrieval that enables the calculation of the yield, biomass, CO_2 and water fluxes components with their associated uncertainties. Next the biomass that returns to the soil simulated by SAFYE-CO2 is used as an input in the AMG soil model. AgriCarbon-EO was applied over the South-West of France covering three Sentinel-2 tiles for major crops (wheat, maize, sunflower) and cover crops. The outputs were validated for several cropping years with independent in-situ biomass, yield and CO_2/water fluxes data measured at several flux towers in Europe. We show the added value of assimilating high-resolution satellite data in driving the crop/soil models to account for the impact of complex processes that are embedded in the LAI signal (e.g. vegetation water stress, disease, and agricultural practices) on the yield, biomass and carbon/water budgets components estimates.

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Changes in soil organic carbon content under annual and perennial crops, and related agricultural practices as observed from a large scale on-farm study in Switzerland

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Abstract: Since 1990, each field topsoil (0-20 cm) of each farm (perennial and annual crops) must be analysed every ten year for Soil Organic Carbon (SOC) content in accordance with international analytical standards, based on a composite sample, as required from Swiss agro-environmental regulation[1]. After data quality control, we used time sequence analyses from about 4000 arable land fields from the cantons of Vaud, Geneva and Jura, and 2000 fields under perennial crops (orchards and vineyards) to quantify the SOC content change rate per year along the past 25 years. We interviewed 300 farmers on a sub sample representative of the cropping systems categories and the overall range of SOC change rates to analyse the relationships between their practices in the past ten years and the observed SOC content change rate. The SOC deficit was quantified based on the soil vulnerability index, namely SOC to clay ratio (Fell et al., 2018; Johannes et al., 2017), with the 10% SOC:clay ratio as minimum desired SOC level. This yielded different deficits ranging from 20% to 80 % of the average SOC content in the Swiss cantons depending on the cropping systems and the soil types, regardless of location and altitude. Vineyards showed the largest deficit. Though the SOC deficit was different between the cantons, the distribution of annual relative SOC change rates was very similar, ranging from -50‰ to +50‰ with a median value close to 0. The average annual change rate, however, was significantly and linearly changing with time, from -4 to -6‰ in the 1995-2000 period to +5 to 10‰ in the present under the different systems with vineyards showing the largest increase. This pattern was identical on all cantons and can be related to the introduction of different mandatory measures in the 1990s such as covering bare soil with green manure, a minimum of 4 crops in the rotation (annual crops), install a grass cover and leave the pruning wood (perennial crops) followed with increasing development of conservation agriculture practices. The detailed analysis of cropping practices and related SOC change rates revealed the major factors allowing for rapid SOC storage and conversely. Moreover, exceptions to the general trends, allowing either to compensate SOC losing practices or jeopardizing storage efforts, were also highlighted. In arable land two performing cropping systems were emerging: polyculture with livestock and conservation agriculture. Gross margins per ha of these systems were equal to or larger than the conventional models. Interestingly, the first positive factor for SOC increase was diversified and intensive cover crops, followed by manure supply. The main negative factor in annual crops was the Soil Tillage Intensity Rating (STIR). The larger the SOC:clay the lower was the effectiveness of the positive factors and the higher the impact of STIR. These results show that the 4‰ COP21 objective is small compared to the actual field-observed results, and the corresponding observations are used to implement the soil carbon sequestration part of the climate plans in the cantons.

[1] https://www.blw.admin.ch/blw/fr/home/instrumente/direktzahlungen/oekologischer-leistungsnachweis.html

Adjustments of the Rock-Eval® thermal analysis for SOC and SIC quantifications

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Abstract:
The standard method to quantify soil organic and inorganic carbon (SOC & SIC) separately in calcareous soils relies on pretreatments (decarbonatation or decarbonation) and calculation of the difference between the C contents measured by Elemental Analysis (EA) on the bulk and the pretreated aliquot (ISO, 1995; Bispo et al., 2017). This procedure leads to i) analytical bias due to pretreatment (*e.g.,* acid pretreatment which is supposed to destroy all the SIC without damaging the SOC), ii) measurement deviation associated with the heterogeneity of the bulk and pretreated aliquots and iii) cumulative errors associated with the calculation (Chatterjee et al., 2009; Schlacher and Connolly, 2014; Nayak et al., 2019). The Rock-Eval® (RE) thermal analysis provides a technical solution to quantify both SOC and SIC with a single analysis on a non-pretreated aliquot (Behar et al., 2001). During the RE analysis, two standard parameters, TOC (for total organic content) and MinC (for mineral carbon), which estimate the organic C and inorganic C contents respectively, are calculated from the carbonaceous effluents emitted by the ramped pyrolysis of the aliquot followed by the oxidation of the residue. The RE analysis was initially developed in the 1970s by IFPEN to study oil bearing rocks. Since the 2000s, the RE analysis has been applied on soil samples and statistical corrections of the TOC parameter have been proposed to improve its estimation of the SOC content assessed by EA (Disnar et al., 2003; Sebag et al., 2022a; 2022b). Thus the RE has been increasingly used to quantify and characterize SOC (Sebag et al., 2016; Soucémarianadin et al., 2018; Malou et al., 2020; Cécillon et al., 2021). However, few applications have focused on SIC quantification and no adjustments of the RE standard analysis cycle have been investigated. This study aims at adjusting the RE standard analysis protocol to quantify SOC and SIC without using statistical corrections. For this aim, a panel of 30 soil samples of southern France and northern Tunisia with a wide range of SOC and SIC contents was analyzed by RE. The results were compared to SOC and SIC quantifications by EA after decarbonatation and decarbonation respectively. First, the total carbon content estimated by RE (TOC + MinC) systematically underestimated the total carbon content estimated by EA for samples with high SIC contents. The higher the SIC amount in the RE crucible, the more the MinC parameter underestimated the SIC content. The oxidation thermograms of crucibles containing more than 4 mg of SIC showed a sudden drop of the CO_2 signal at the end of the analysis suggesting an incomplete thermal breakdown of the carbonates. Thus, the last oxidation isotherm was extended to achieve the SIC thermal breakdown (Hazera et al., 2023, in prep). Secondly, the pyrolysis thermograms showed that, after 550°C, a part of thermoresistant SOC and a part of SIC decomposed simultaneously. To avoid the fluxes mixing and the use of statistical corrections, the pyrolysis phase was stopped at the onset of SIC decomposition to drag all SIC signal during the oxidation phase only. The

parameters obtained with this cycle of analysis are strongly related to those obtained with the standard cycle and the statistical corrections. Finally, the new cycle of RE analysis (extended oxidation and low temperature pyrolysis) improved the SOC and SIC content estimations by the TOC and MinC parameters on a single aliquot of calcareous sample and without using statistical corrections.

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Quantification of biochar in arable land: a new approach with Rock-Eval® thermal analysis.

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Abstract:

Biochar, the solid residue of pyrolyzed organic material, is considered as a negative emission technology (Smith 2016). When applied on soils, biochar was shown to additionally improve plant yields and soil physical environment (Blanco-Canqui 2017; Kavitha et al. 2018; Zhang et al. 2021). Therefore, biochar has attracted lots of attentions in agricultural fields. However, biochar particles are highly mobile in soils (Chen et al. 2017), which raises questions about the fate of biochar over long-term scales. Quantifying biochar apprears as necessary to help monitoring its fate in soil. However, the technical methods allowing biochar quantification are still time consuming or imprecise. In our study, we propose a new approach to quantify biochar when mixed with agricultural soil, based on their thermal properties. We used six industrial biochars from plants and four cultivated soils mixed at five different biochar/soil ratios (from 0.05 % to 1 % (w/w)), that we analysed using the Rock-Eval® thermal method.

Our results showed that the CO_2 emissions during oxidation stage of the Rock-Eval® analysis (CO_2oxi) presented a peak between 430 and 630 °C, that increased along with biochar quantities in the mixtures. In this range of temperatures, the difference between CO_2oxi emissions from the mixture and from pure soil samples was well correlated with the carbon content from biochar in the mixture. Hence, we showed that the Rock-Eval® thermal method was a good tool to quantify biochar in cultivated soils, using the CO_2oxi emissions. However, this method requires data from pure soil samples. Further research would be needed to adapt this protocol to the cases when pure soil sampling is not possible and/or when biochar is mixed with non-cultivated soils.

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Session 1

ABSTRACTS of POSTERS

Rock-Eval® device for characterization of environmental samples: methods, insights, and applications.

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The Rock-Eval® device is an open-system pyrolysis and oxidation instrument that has been primarily developed to characterize the thermal properties of the sedimentary organic matter using different standardized analytical methods. This device was mainly used to investigate the potential of source rocks for petroleum system explorations (e.g., Espitalié et al., 1977; Espitalié et al., 1986; Lafargue et al., 1998; among others). It has been also used to quantify the total organic carbon (TOC) and the mineral carbon (MINC) contents of any sedimentary rock. Since the 2000s, this technique has been increasingly tested in other geoscience applications including: (1) the characterization of organic matter in soils (e.g., Di-Giovanni et al., 2000; Disnar et al., 2003; Sebag et al., 2006); (2) the study of past climate changes and global carbon cycle (e.g., Baudin et al., 2007, 2010; Rohais et al., 2019; Garcin et al., 2022), (3) the determination of the origin of geothermal scales (Romero-Sarmiento et al., 2022a) and recently (4) the quantification of microplastics in sediments displaying different mineral matrix (Romero-Sarmiento et al., 2022b). Most of these environmental applications required adjustments of the standard Rock-Eval® analytical methods as well as of the signal treatment and interpretation to obtain more accurate and appropriate thermal parameters.

The aim of this work is to summarize these good practices to better characterize environmental samples from different case studies, especially in the framework of the ecological transition. For instance, specific thermal and quantification procedures are now proposed to quantify both organic and inorganic carbon contents in calcareous soils (Sebag et al., 2022; Hazera et al., 2023). For soil samples showing very low organic carbon content, an alternative methodology is also proposed based on the Rock-Eval® oxidation stage only to better quantify the soil organic carbon content (Malou et al., 2023). Furthermore, oxidative emissions from Rock-Eval® device can be used to characterize carbonized biomass (Aubertin et al., in prep). Moreover, some Rock-Eval® parameters seem to be suitable to evaluate the fertilizing or amending effect (IROC% equivalent) of biowaste (Ducasse et al., 2023, Wei et al., in prep). Finally, a quick conversion approach using Rock-Eval® parameters to distinguish polymer families is proposed to quantify the polymer content in natural samples contaminated by plastics (Romero-Sarmiento et al., 2022b), as well as Rock-Eval® pyrolysis parameters are also proposed to follow the impact of plastics on carbon mineralization in soil ecosystems (unpublished internal data). In this work, analytical recommendations about the Rock-Eval® method are therefore provided regarding the nature, the origin, and the geochemical context of the investigated environmental samples.

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Carbon Farming practices verified by Rock-Eval soil analysis

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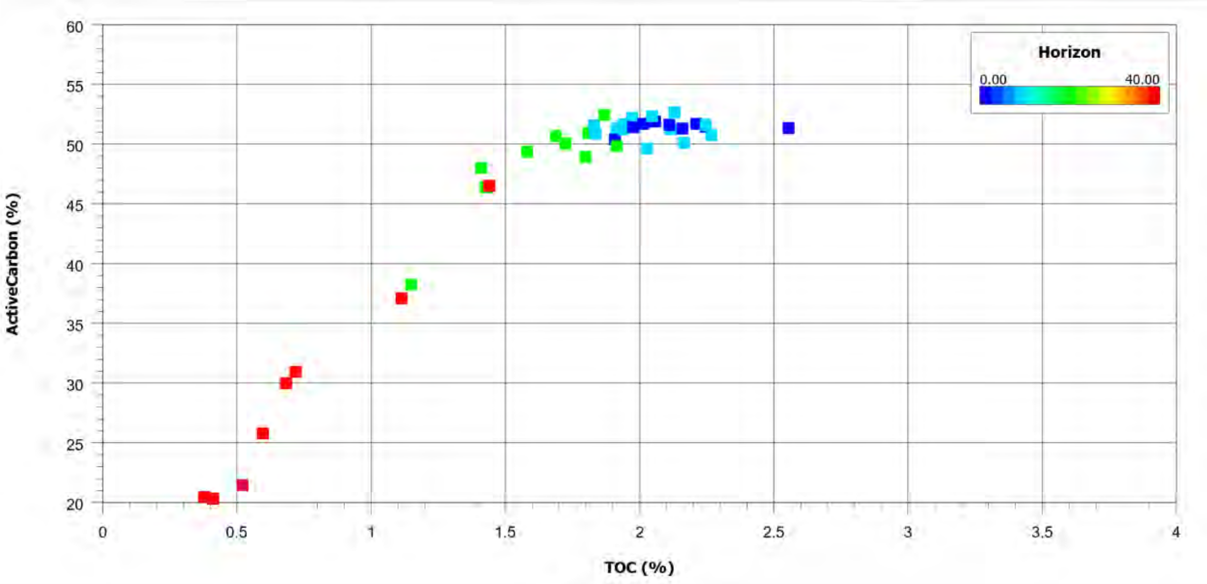
The Terrasolis experimental farm is located on a limestone plateau, historically a land without any agriculture (a moor or heath).

Total Organic Carbon (TOC) measurements indicate relatively typical values for large-scale farming plots, ranging from 0.5% to 2.5%. However, PartySoc data reveals that stable carbon content is not as high as the 60-65% found in traditional large-scale crop cultivation soils, but rather only 50%. This suggests that the original land has been recently converted for farming, a hypothesis confirmed by historical aerial views.

The natural tendency of soils to exhibit lower TOC values with increasing depth is observed throughout the Terrasolis farm, across all plots. Similarly, Total Inorganic Carbon (TIC) increases with depth as it approaches the bedrock. Furthermore, as soil horizons are deeper, the organic matter gets more oxidized, due to life activity, resulting in increased stability.

Furthermore, Rock-Eval measurements reveal significant differences between various plots. These differences are already known to the farmers and corroborate previous pedological and resistivity measurements. This study highlights the usefulness of carbon fractions content as a reliable proxy for other soils parameters, as already reported by the Microbioterre project.

Monitoring the evolution of the Terrasolis farm's soils over time will be an interesting endeavor.


Horizon
0.00
40.00
ActiveCarbon (%)
TOC (%)
60
55
50
45
40
35
30
25
20
0
0.5
1
1.5
2
2.5
3
3.5
4

Effects of mechanical site preparation techniques in forest plantation context on the soil organic carbon stocks and on the priming effect process.

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For the forest stand renewal phase, Mechanical Site Preparation (MSP) can be applied to promote the forest plantations establishment (Collet et al., 2014). Nevertheless, MSP results in soil disturbance and interferes with soil organic carbon (SOC) stocks (Mayer et al., 2020). Alternative MSP techniques are now being proposed to reduce the impact on soil properties and thus preserve the carbon sequestration function of forest soils (Pellerin et al., 2020). This thesis project aims to (i) test different MSP techniques of variable tilled area on SOC destorage, (ii) identify a short-term response of SOC stocks to MSP over a textural gradient, (iii) measure how the SOC redistribution following MSP influences the SOC mineralization process. In the short term, we assume (i) that MSP localized to a reduced surface area does not significantly impact SOC stocks at the forest stand scale, (ii) that SOC destorage in tilled area is greater in clay-rich soils and (iii) that SOC redistribution following MSP causes overmineralization through the priming effect process. Three complementary approaches are used: (i) an *in situ* block experiment testing five MSP modalities of gradual intensity in terms of tilled surface (initial state before MSP then monitoring over 2 years during the thesis), (ii) a sampling before and after MSP on a panel of twelve sites being renewed constituting a textural gradient of clay content to gain in genericity compared with the *in situ* experiment, (iii) a controlled laboratory experiment on soil cores from the modalities of the *in situ* experiment, on which a C4 plant will be grown in order to monitor the mineralization process using the natural isotopic signature (13C) of C4 plants. From these approaches, we expect our results will show a significant effect on SOC stocks proportional to MSP intensity, a more significant decrease in top soil layer in sites with high clay content, and a priming effect proportional to MSP intensity.

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Assessment of C storage of a Technosol under short rotation coppice management

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Technosols contribution to C storage have been seldom considered. However, a recent study highlighted their relevance for C storage (Allory et al. 2022). Indeed, with an average C content in the first 30 cm of 4.3% and soil organic carbon stock of 73 t ha^{-1}, this soil category might be a real asset to contribute to the overall carbon storage of the soil compartment. These high values are mostly explained by the “recent” history of these soils and the significant contribution of the artefacts they contain. These materials, created, substantially modified or brought to the surface by humans, can contain high quantities of carbon explaining the high, sometimes extreme, C content values measured. These materials might have been introduced to Technosols through mining and urban activities (e.g. wood, charcoal, coal, coked-coal, asphaltic concrete), or restoration and reclamation processes (e.g. compost, biochar, sewage sludge). For some of these artefacts their formation, either natural for fossil material, or industrial for charcoal, coke or biochar, has strongly stabilized the organic matter and the corresponding C compartment can be considered as stable. The main scientific issues are then i) to assess the effective stability of this “stable” anthropic organic matter and ii) to evaluate its interaction with freshly added natural organic matter and potential stabilizing ability.

To do so, a pilot soil plot was set-up consisting of 1 m profile of mixed moderately contaminated soil. A short rotation coppice of *Robinia pseudoacacia* and *Alnus incana* was implemented in March 2019 together with a mixed soil cover of *Medicago sativa* and *Phacelia tanacetifolia*. Over the 2.5 following years soil carbon content and stocks along with physical and chemical soil properties and vegetation evolution were measured. Transfer of residual pollution was assessed as well to insure the innocuity of the overall phytomanagement process.

To date, the length of the monitoring period remains too short to draw definite conclusions regarding the additional carbon storage capacity of such Technosol. These systems present a high spatial variability and the intrinsic nature of the C along with the high C content result in analytical issues. To partly overcome these difficulties, an analytical approach using Rock-Eval® analysis has been tested. It enables to discriminate between original stable anthropic C and freshly added biomass from plant cover and/or initial compost amendments. As a result, the pilot plot displays high C storage capacity and both mineral and organic artefacts appear to offer stabilizing surfaces to freshly added C. Moreover, in depth C storage can also be achieved.

The SOC:clay ratio – a measure of the organic carbon saturation of soil indicative of its potential structural stability

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The soil organic carbon:clay (SOC:clay) ratio is more and more considered as a key indicator for the monitoring and management of agricultural soil quality. It has the advantages to: (i) provide a measure of the organic carbon saturation of soil and (ii) be closely related to soil structural quality. Accordingly, the SOC:clay ratio has been proposed as an indicator for the monitoring of soil organic matter loss in the *Proposal for a directive on soil monitoring and resilience* of the European Union[1] and for the implementation of a new agri-environment-climate measure (AECM) of the common agricultural policy (CAP) 2023-2027 in Wallonia, Belgium[2].
In this work, we aimed to assess how the SOC:clay ratio relates to: (i) SOC stocks; and (ii) soil structural stability of agricultural soils of central Belgium subject to various soil management practices. To meet this goal, we collected the soil of 42 agricultural plots with contrasting farming practices in four long-term field experiments (LTEs) of the agricultural domain of the Walloon Agricultural Research Centre, in the loess belt of Belgium. LTEs include arable crop and market gardening systems with a diversity of soil management practices regarding crop rotation, tillage, organic inputs, fertilization, and intercropping cover. The soil of each plot was sampled up to 1 m for five fixed depths (0-10, 10-25, 25-50, 50-75, and 75-100 cm) with gouge augers of known diameter to calculate SOC stocks by the equivalent soil mass method. SOC content was measured by dry combustion with a correction for inorganic C when necessary. Clay content was determined by sieving and sedimentation, according to Stokes law (norm NF-X31-107:2003). For the measurement of soil structural stability, structured topsoil samples of about 100 cm³ were collected with Kopecky cylinders at a depth of 1-6 cm. Soil structural stability was estimated by the QuantiSlakeTest (QST) method[3], consisting in the dynamic weighting of soil under water and a quantitative interpretation of the resulting curve.
Total (14000 t/ha, corresponding to approximately 0-100 cm) SOC stock ranged from 54.9 to 117.8 t/ha, with the topsoil (2700 t/ha, corresponding to approximately 0-25 cm) contributing from 37 to 74 % of total SOC. SOC stocks appeared to be mainly related to the cropping history of the plot and to organic inputs. Topsoil SOC:clay ratio ranged from 0.047 to 0.168 and correlated strongly with total SOC stock (r=0.76). Nevertheless, this correlation was smaller than that between topsoil and total SOC stock (r=0.91), despite the small range of clay content at the scale of our dataset. This result underpins that the SOC:clay ratio provides a measure of the carbon saturation of soil with no straightforward link with the absolute SOC stock.

[1] https://environment.ec.europa.eu/publications/proposal-directive-soil-monitoring-and-resilience_en
[2] https://agriculture.wallonie.be/home/aides/pac-2023-2027-description-des-interventions/mesures-agro-environnementales-et-climatiques/maec-sol-a-partir-de-2024.html
[3] https://doi.org/10.5194/egusphere-2022-1092

Soil structural stability related mainly to tillage and soil cover. Overall, the SOC:Clay ratio correlated poorly ($r < 0.36$) with soil structural stability, regardless of the indicator calculated from the QST curves. This result contrasts with the strong correlation ($r = 0.93$) obtained for standardized conditions of soil preparation (rotary harrow + seed drill) and cover (winter wheat) in a previous campaign in 2019. This underlines that the SOC:clay ratio is an indicator of the "potential" structural stability of soil, whereas the expression of soil structural stability also depends on external factors such as tillage and crop development.

Soil Carbon in the Ecological Transition
International symposium
24 - 26 January 2024

Assessing the carbon fluxes in perennial and annual grass systems using both automatic and manual chamber methods

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Abstract: Assessment of carbon (C) flux dynamics are critical for advancing the understanding of the biogeochemical cycle in agricultural soils. Conventional agricultural systems have been intensified during the last century to feed the increasing world population at the expense of terrestrial C loss. Perennial cropping systems may shift agricultural crop production from C-source to C-sink. However, large uncertainties and difficulties are related to C flux measurement. This study aims to quantify the C fluxes in a replicated field experiment established with annual grain crop and perennial grass systems in 2012 using both automated and manual chamber methods. Both methods combine the net ecosystem exchange and ecosystem respiration for calculating the gross primary productivity. Moreover, we also deployed automated and survey soil respiration chambers in order to separate soil respiration into autotrophic and heterotrophic components. The automated chambers secured data with high temporal resolution in one of the field replicates while the manual chamber was able to cover the field variation, represented by the four field replicates, with low temporal resolution. Annual estimates of net carbon balances and below-ground biomass production of the different cropping systems will be presented.

Session 2

STABILISATION OF SOIL ORGANIC MATTER: A CENTRAL PROCESS IN C-STORING AGRICULTURAL PRACTICES

Storing additional carbon in soil: different practices, different stabilities of the organic matter?

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A diversity of agricultural practices and systems enable the accrual of soil organic C (SOC) stocks, with variable efficiencies. These C-storing practices increase SOC stocks, either by increasing the inputs of plant biomass or exogenous organic matter, or by decreasing the outputs of SOC reducing SOC mineralisation rates, or both. In the perspective of contributing to climate change mitigation, the temporal stability of the additional SOC stored is critical.

Different approaches can be used to assess the stability of soil organic matter, such as physical fractionation of soil organic matter, chemical extractions, long term incubations and analysis of the thermal behaviour of the organic matter using Rock-Eval® analysis. These address contrasting residence times, such as of months to years (long term incubations), to several decades and centuries (particle size fractionation, Rock-Eval® analysis coupled with PARTYSOC model)

We used the literature and long-term agricultural experiments in which management options (application of exogenous organic matter, conservation agriculture, organic agriculture, agroforestry) result in increased SOC stocks. We investigated the stability of the additional SOC stored, compared to the reference management option.

Methods currently used in the literature to assess the temporal stability of soil organic matter do not address the same SOC kinetic pools. Care must be taken to specify which range of residence times is considered when using any method intending to evaluate the biogeochemical stability of soil organic matter, as well as when using the terms stable or labile.

Management options result in slightly contrasted stability of the additional organic carbon, the application of exogenous organic matter resulting in the most stable additional carbon, compared to management options that increase belowground plant biomass inputs to soil. Carbon storing agricultural management options mobilize different stabilization processes of soil organic matter: chemical recalcitrance, organo-mineral interactions and physical protection.

About some current controversies on mechanisms controlling carbon storage in soils

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Abstract :

Increasing organic matter (OM) storage in soils has a positive effect on climate change by alleviating the amount of C transferred from the soil to the atmosphere as CO_2 or CH_4, and should therefore be favored when making decision about soil management practices. It can result either from additional OM inputs, or from preservation mechanisms reducing C loss from soil. However, there is still a lack of consensus in the scientific community on the mechanisms controlling C storage.
We discuss here some of the current antagonistic views on several mechanisms driving C storage in soils: chemical recalcitrance, microbial transformations leading to C persistence in soil and the contribution of particulate organic matter to additional C storage. We propose that the different conflicting theories can often be reconciled by considering ecosystem properties. We also recall that while our community focuses on how biomass-derived soil OM can contribute to climate change mitigation, we should keep in mind the alternative fate of plant biomass. Harvested biomass of course contributes to food security but also to climate mitigation through the production of bioenergy and biomaterials as a substitute for fossil resources. The trade-off between exporting biomass or maintaining it in the ecosystem for soil organic matter accrual must take into account these global challenges of food security, climate change mitigation and soil sustainability, together with socio-economical constraints.

Reference: Derrien et al. ASD 2023

Saturation of clay surfaces by organic matter: consequences on physical, chemical and microbiological properties

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Abstract:
Clay minerals are considered to protect organic matter (OM) from degradation by microorganisms and therefore to contribute to carbon sequestration in soils (Kleber et al. 2021). Recent studies showed contradictory results on the limit of mineral-associated organic carbon in agricultural soils (Georgiou et al., 2022; Begill et al., 2023; Cotrufo et al., 2023), suggesting that fine-scale processes are not yet well understood. This study aimed to determine the maximal capacity of different types of clay minerals to stabilize OM and evaluate the consequences on physical, chemical and microbiological properties. To this aim, we conducted a laboratory experiment using 3 types of clays differing in their specific exchange surfaces: kaolinite (30 m²/g), montmorillonite (250 m²/g) and sepiolite (600 m²/g). Each microcosm (100 ml) consisted of the same 10 g ratio of sand (80%) and each type of clay (20%) mixed with different amounts (1, 5, 10, 25 or 50%) of green waste compost (GWC) in order to test the saturation of mineral surfaces. After 6 months of incubation, during which CO_2 emission was monitored weekly, we measured the water holding capacity, chemical parameters like pH and cation exchange capacity (CEC), and the microbial biomass by qPCR. Interactions between clay minerals and OM were also observed with the scanning electron microscope (SEM). As expected, mesocosms respiration measurements showed the lowest CO_2 release in sepiolite treatments, compared to montmorillonite, kaolinite and the control without clays. The large specific surface of sepiolite inevitably impacted microbial growth. The effect of clays on the OM mineralization was observed up to 5%, 10% and 25% of GWC in the mix, respectively with kaolinite, montmorillonite and sepiolite, suggesting that above these amounts of OM, mineral surfaces were saturated. SEM analyses revealed that without clay minerals, OM matter remained as particulates (POM), whereas in the treatments with kaolinite, montmorillonite and sepiolite addition the mineral-associated OM (MAOM) were visible. Results showed the highest water retention in sepiolite treatments and with increased doses of compost, kaolinite and montmorillonite treatments remained on the same level. CEC and pH also varied significantly after the incubation, suggesting changes in physicochemical properties due to OM stabilization and interaction with clays. The microbial biomass, either bacteria or fungi, followed the amount of CO_2 released, suggesting that the accessibility of OM by microorganisms was limited by clay minerals, depending on their nature and saturation capacity. Ongoing Rock-Eval pyrolysis will help to characterize the chemical composition of the organo-mineral complex in order to determine if the physical protection of OM is associated with chemical change. Microbial community structures assessed by means of amplicon next-generation sequencing (NGS) will also inform on microbial qualitative change according to OM stabilization.

Annex :

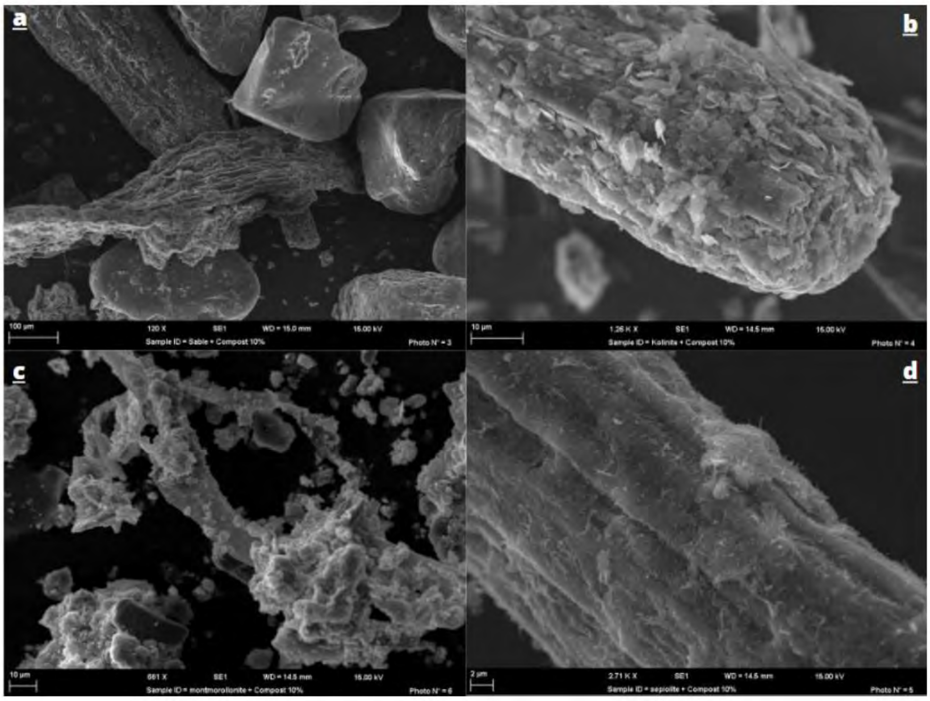

Figure 1: Scanning electron microscopy (SEM): sand (a), kaolinite (b), montmorillonite (c) and sepiolite (d) with 10% compost after 6 months of incubation.

Organic matter quality in arable land as influence by clay content and cropping system

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Abstract:

Fifty fields from the Swiss plateau, cropped with Conservation Agriculture (CA) or conventional tillage (CT) since at least 10 years, were sampled for structure quality and soil analyses down to 40 cm depth. The organic matter (OM) quality was studied with Rock-Eval analysis. The relationships between cropping practices, depth, clay content, Soil Organic Carbon (SOC) content and OM quality were then discussed. CA and CT differed mostly by the location of SOC, with higher content on the topsoil in CA, and lower below 20 cm depth, compared to CT. OM quality was influenced by SOC content, showing increasing labile forms proportion with increasing SOC content. SOC to clay ratio, however, seemed to be the major determinant of OM quality, with the 0.1 ratio corresponding to a threshold above which changes in SOC content are mostly accounted for by labile forms, and conversely. This 0.1 SOC:clay ratio was already highlighted as a threshold for structural and physical behavour of the soil, thus leading to the hypothesis that the degradation of mid-recalcitrant forms under this ratio are responsible for structure degradation. Moreover, these results call for caution when interpreting field experiments with respect to OM quality, which appears to be driven by SOC:Clay ratio rather than cropping practices in this study.

Thermo-chemical characterisation of organic matter in agricultural soils subjected to long-term chemical or organic fertilisation

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Abstract:
Any agricultural practice that increases organic matter (OM) inputs into soils has a positive effect on C stocks, either directly through organic amendments, or indirectly through the stimulation of plant biomass by chemical fertilisation. However, the mechanisms involved are not yet clearly understood, which is why it is important to be able to assess the influence of organic or chemical fertilization on the nature and chemical properties of OM that are linked to their dynamics in soils. In this study, soil samples were collected from Ultuna's experimental fields in Uppsala, Sweden. The plots have been cultivated with cereals since 1956 and have received different types of fertilisation (mineral and/or organic), including bare soil, unfertilised, fertilised with calcium nitrate, amended with straw, straw + calcium nitrate, green manure, manure, peat and sludge. Organic fertilisation is applied every other year (autumn) in the form of 8 tons of fresh OM per hectare. Mineral fertilisation is applied every year (spring) with 80 kg of nitrogen per hectare. A series of analyses were carried out to determine the abundance, genetic and catabolic diversity of the microorganisms (Lerch et al., 2013; Blaud et al., 2015; Changey et al., 2020). In addition, incubations under controlled conditions were carried out to obtain OM mineralisation kinetics. These data suggest strong changes in microbial communities, both structurally and functionally. These were related to soil pH and changes in OM quality. Rock-Eval® thermal analysis revealed that treatments that had increased the most the C content over the last 50 years (peat, sludge or manure) were related to soil OM with the highest hydrogen index (HI). Mid-infrared spectrometry (MIRS) and solid-state nuclear magnetic resonance (^{13}C-NMR) analyses also suggest that the chemical quality of OM influences its decomposition by microbial communities. GC-MS pyrolysis allowed to estimate the relative contribution of the different families of molecules as a function of the treatments. Here, we observed that the biogeochemical stability of soil OM was related to higher proportion of lipids and aromatic compounds.

Organic matter stabilization in constructed soils manufactured with clay-rich waste.

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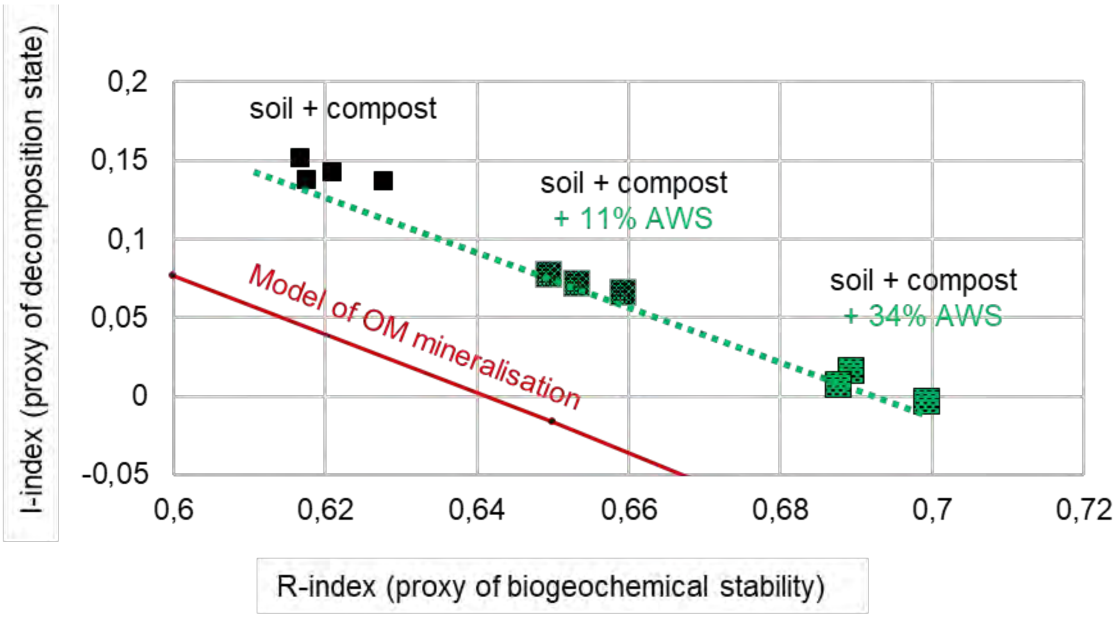
Abstract:
Soil is a fundamental and finite resource that fulfils a number of functions and services crucial to the health and well-being of the planet and all ecosystems. Humans are integral components of the global ecosystem. As climate change risks continue to intensify, it becomes imperative to thoroughly investigate the advantages of efficient soil management and the role of waste materials in enhancing soil quality within a circular economy. Soil degradation has emerged as a critical and growing global issue. One potential approach to address the erosion and depletion of topsoil involves the formulation of soils from otherwise waste materials, to restore healthy and functioning soil. These soils are referred to constructed soils and their applications include manufacture of topsoil for agriculture. Waste materials, e.g. clay-rich waste materials, can be used in constructed soils due to their capacity to enhance soil structure, soil moisture content and soil agronomic properties. Furthermore, there is a prevailing assumption that the inclusion of clay materials can protect a proportion of soil organic matter (SOM) from biogeochemical degradation.
In this study, we seek to investigate whether certain clay-rich waste materials can indeed contribute to enhancing the biogeochemical stabilization of SOM. Our research was conducted within the framework of the INTERREG project ReCon Soil at the Caté applied research station (Brittany, France). Constructed soils were formulated by mixing aggregate washing sludge (AWS) obtained from a quarry close to Caté with agricultural soil coming from Caté. They were set in ~1m^3 outdoor lysimeters. The following proportions were used: respectively 34 % and 11 % of AWS, mixed with 66 % and 89 % of agricultural soil from Caté. These mixtures were further amended with green waste compost at a rate of 30 t/ha. A control was set by using 100% of agricultural soil from Caté also amended with green waste compost at the same rate. Lettuce (little gem, cv. Alborada) were grown on these soils for 9 months (3 growing cycles). Following the final harvest, we measured soil CO_2 fluxes at the soil/atmosphere interface for each lysimeter to assess soil respiration processes in the soil. Flux measurements were obtained using the accumulation chamber method (Echo Instruments) with external recirculation. Then, topsoil (0 – 5 cm) samples were collected for performing biological, chemical and physical analysis. SOM status was assessed through ramped pyrolysis using the Rock-Eval® method. The Rock-Eval® data were treated to plot the I-index (thermal decomposition) as a function of R-index (thermal stability).
The Rock-Eval® results suggest that biogeochemical stability of SOM increases with addition of AWS (see annexed figure). These results were correlated with CO_2 flux measurements for the soil with 11% of AWS, since CO_2 emissions coming from this modality were significatively lower than the soil without any sludge. Our preliminary results enable us to conclude that AWS seems suitable to increase SOM stabilization, but these results will be confirmed by forthcoming microbiological analyses.



The I-index quantifies the relative quantity of hydrocarbons present in labile OM, while the R-index quantifies the relative quantity of hydrocarbons in both resistant and stable OM, during Rock-Eval® pyrolysis. These indices serve as proxies for assessing the decomposition state and biogeochemical stability, respectively.

Figure: Stability status of organic matter within the soil+compost+AWS mixtures after 9 months of lettuce cultivation

Whole soil warming promotes subsoil carbon gain depending on land management practices in temperate climate

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Abstract:

Global warming has the potential to stimulate soil microbial metabolism and enzymatic activity, which leads to the acceleration of biogeochemical processes and may influence soil carbon sequestration. However, the direction and magnitude of these changes are uncertain, as deep soil microbial community and enzyme activities are poorly constrained. In particular, management effects on the warming responses of microbial communities at depth are unknown. Here, we conducted an in-situ soil warming (+4°C) experiment down to 2.0-m depth in an agricultural Cambisol to study the warming responses of soil properties, extracellular enzyme activity, eco-enzymatic stoichiometry, and microbial community composition under two different land management practices.

Our findings indicate that one year of soil warming altered the carbon and nitrogen contents, depending on soil depth and land management practices. Interestingly, we found that warming had no effect on topsoil C and N content for both land management, while subsoil (>30 cm) showed a contrasting response to warming: it significantly increased for cropland but not for grassland. These findings imply that the effects of warming on soil C and N content are likely to be influenced by how land is managed and the depth of the soil being studied. We also detected a contrasting trend of warming responses for soil microbial communities and enzyme activities, which were dependent on soil depth and land management practices. Likewise, our results indicate that microbial resource limitations shifted in warmed soil with land management and soil depths. These findings imply that the effects of warming on biogeochemical cycling and C storage are likely to be influenced by depth and management practices. Overall, our study suggests that sustainable land management fostering deep soil C accrual may be a possible solution (short-term) to preserve more C in the soil-system in response to elevated warming to combat future climate change.

Session 2

ABSTRACTS of POSTERS

Effect of agricultural management practices on soil structural stability and organic matter deprotection during drying-rewetting cycles

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Abstract:

Increasing drought conditions, as a result of climate change are expected to cause more frequent and intense drying-rewetting cycles in soils. Peaks of CO_2 emissions released from the soil to the atmosphere during the rewetting phase have been well documented. One hypothesis for this carbon release is the physical deprotection of organic matter in soils due to modifications in the soil structure, particularly regarding the pore network morphology. The morphological stability of the soil during drying-rewetting cycles depends of the soil properties (e.g. texture, carbon content), but is also expected to depend on soil management practices in agroecosystems.

This work aims to reveal for the first time the physical deprotection of organic matter in natural soils. We used synchrotron-based X-ray imaging to measure the temporal evolution of the 3D spatial distribution of organic matter in soil samples during drying-rewetting cycles. Soil samples were collected from the 2-5 cm layer of two Luvisols under conventional and conservation agriculture respectively. The samples were air-dried and broken manually into aggregates of 2-3 mm, and their organic matter was stained with Osmium. Then, 18 aggregates were subjected to 3 drying-rewetting cycles and scanned at 1.3 µm resolution before and after rewetting. The rewetting phase was also captured using 1 second fast scans performed at regular intervals over 10 minutes at 2.2 µm resolution.

The visualisation of short-time soil structure dynamics during the rewetting period allows us to observe the formation of microcracks during drying and wetting events. Soil structure deformation is affected by agricultural practices: more intense deformation occurs under conventional agriculture compared to conservation agriculture, especially during the second and third drying-wetting cycles. Aggregates from conservation agriculture show less swelling, thinner cracks, and better structural recovery upon drying. Aggregates from conservation agriculture contain more Osmium-stained organic matter. Further steps of this project will quantify interactions between the organic matter and the changing pore network during drying-rewetting cycles, and infer new relationships between soil organic matter decomposition and soil structure dynamics.

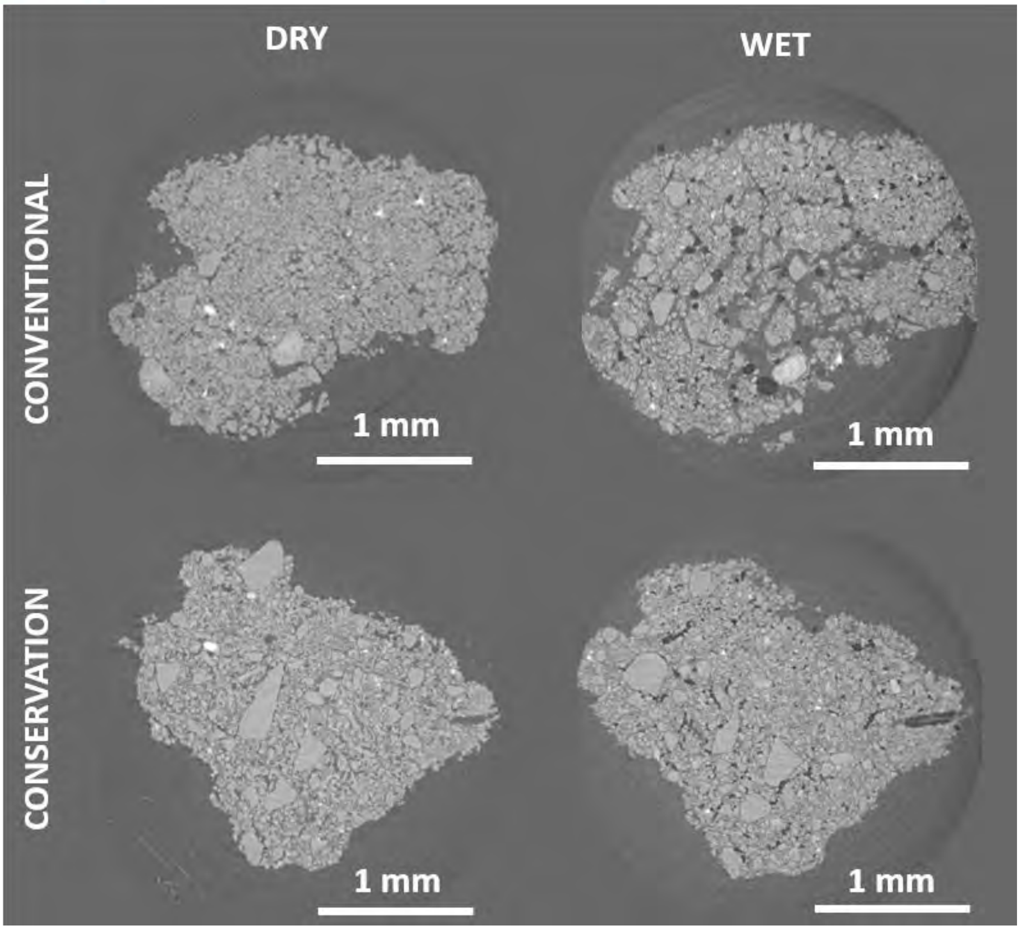

Figure: Visualisation of aggregate structure before and after rewetting for conventional and conservation agriculture

+ 1 annex accepted: image, graph or table

Dynamic of soil organic carbon pools in cacao-based agroforestry systems of Divo (Côte d'Ivoire)

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Abstract

Soil is a major carbon pool at the global scale. It can also act as a carbon sink or source, based on their properties, climate and management methods. Adopting sustainable agricultural practices such as agroforestry could help to increase the soil's organic matter content and carbon sequestration and even countering, anthropogenic greenhouse gas emissions. The choice of tree species to be associated with cacao trees seems to be essential to the efficiency and sustainability of this system soil carbon storage. Potassium permanganate oxidizable carbon (POxC) and basal soil respiration (SituResp) are indicators of organic carbon dynamics that could be influenced by organic matter fluxes in cacao system. This raises the question of the long-term impact of cacao-associated tree systems on soil organic carbon dynamics, especially when specific tree species as legume trees are involved. The study was carried out in a four-block randomized experimental design in Divo (Ivory Coast, West Africa). It involved cacao-*Albizia lebbeck* (Cacao-Alb) and cacao-*Acacia mangium* (Cacao-Aca) intercrops, and unshaded cacao plots (Control). After 20 years of intercropping, we assessed the impact of associated shade tree legume (ATL), *A. lebbeck* and *A. mangium* in cacao stand on soil organic matter dynamic (at 10 cm depth) at various distances from ATL (D1: 0-1.75m; D2: 3.25-5m and D3: 7-9m).

The results indicated a higher SOC stock and PoxC content under Cacao-Alb compared to Cacao-Aca and Control treatments. However, Cacao-Alb recorded a trend of SOC mineralization, especially farther away from the ATL trunk. Cacao-Aca, recorded the lowest SOC stock, with a significant decrease as compared to Control and a higher POxC. The results under *A. mangium* could be attributed to both a lower carbon input due to the quality of its litter and an increased mineralization, particularly farther away from the ATL trunk. Unlike the Cacao-ATL plots, the Control plots tended to accumulate carbon. However, SOC mineralization was more prominent in Cacao-Aca plots than in Cacao-Alb plots. These contrasted results between the two ATL species, could be explained by the litter quality reflected by lower C/N and C/P ratios produced by *A. lebbeck*.

Keywords: Cacao agrofrestry systems; Tree legume; *Acacia mangium*; *Albizia lebbeck*; soil organic carbon; POxC-SituResp® indicator.

Influence of different agricultural managements on soil organic matter distribution and stability in topsoil and subsoil.

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Soil plays a crucial role as a global reservoir of carbon (C) for ecosystem functioning. Soil organic C sequestration can have multiple benefits, including restoring soil functions, offsetting anthropogenic C emissions and mitigating climate change, improving soil resilience, increasing agricultural productivity and sustainability, and enhancing food security. Because of the potential benefits, many studies have focused on determining which practices should be favoured for increasing soil organic carbon (SOC) in the agroecosystem. To increase stabilization and storage of SOC, conservative soil management strategies such as improved crop rotation, organic fertilization, increased buried crop residues, minimum or no tillage and permanent grass cover, are considered the most effective. Besides management practices, SOC accumulation is highly dependent on climate and soil properties, according to the climatic region and soil type, respectively. Soil properties and C dynamics also change depending on the considered soil depth. SOC content is normally larger in the upper horizons, where microbial activity, aeration, and soil disturbance are higher. Therefore, subsoil could be more suited to long-term C sequestration than topsoil.
The aim of our study was to investigate how different agricultural management systems influenced the functional pools of soil organic matter in topsoil and subsoil of a Cambisol located in Umbria plain, central Italy. The research was conducted in a mid-term (10 years) wheat-maize rotation field where three different cropping systems were applied: 1) integrated conventional management with no cover crop and conventional tillage, 2) organic management with cover crop and conventional tillage, 3) conservative integrated management with cover crop and no tillage. Within each plot, soil profiles were dug reaching 60/70 cm of depth and A (Ap1, Ap2) and B (Bw1, Bw2) horizons were sampled. The soil samples were characterised (texture, pH, organic C and total N contents) and subjected to a combined physical and chemical fractionation which allow us to obtain the following organic matter (OM) pools: active (water-extractable and particulate OM), intermediate (OM associated with stable sand-size aggregates and silt- and clay-size aggregates) and passive (OM resistant to oxidation).
The comparison among the distributions of the different organic pools will provide a preliminary indication of the potential for organic C stabilization of the three tested agricultural managements systems.

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Changes in chemical composition of humic substances during microbial composting and Agaricus bisporus mycelial growth

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The substrate production process for the edible mushroom Agaricus bisporus can serve as a model environment to investigate organic matter transformation by microbes. Until now, insights in chemical compositional changes of humic substance (HS) throughout the substrate production process are scarce, and their nutritional properties for the fungus are unknown. To reveal these compositional changes, dissolved and solid HS were extracted with water and acid/base, respectively, from bulk material harvested throughout the microbial composting and mycelial colonization of A. bisporus. Total carbon and nitrogen were analyzed in bulk material and corresponding HS fractions, while bulk material was also analyzed for carbohydrates, fatty acids, and lignin content and composition. Isolated humic acids (HA), fulvic acids (FA), and bulk material were further analyzed by pyrolysis-GC-MS. Throughout microbial composting HS increased substantially, with HA as main fraction followed by FA. The HS increase was accompanied by a high lignocellulose decrease and enrichment of organic nitrogen, as shown by analysis of bulk material and concurrent HA and FA isolates. HA was particularly rich in lignin(-like) and nitrogen compounds. At the early stage of A. bisporus colonization, HS, and particularly HA, decreased, which suggests the importance of HA as fungal carbon and nitrogen nutrient source.

Characterization by thermal analysis of soil organic matter storage induced by organic amendments

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Due to the increasing societal demand for the development of renewable energy sources and CO_2 mitigation, new agricultural practices are emerging, such as anaerobic digestion to produce biogas, soil conservation agriculture, and the advancement of organic matter treatment through pyrolysis. These novel practices result in the reintroduction of more biomass (cover crops), along with various residual organic matters (anaerobic digestion digestates, organic waste compost, biochars), and may induce Soil Organic Carbon (SOC) sequestration. Soil Organic Carbon (SOC) sequestration can contribute to partly offsetting greenhouse gas emissions, and mainly to increased soil quality and climate change adaptation *(Rumpel et al., 2020)*. Thus, there is a need for credible and reliable measurement/monitoring, reporting and verification platforms, both for national reporting on SOC storage, soil quality and for emissions trading *(Smith et al., 2020)*.

The Rock-Eval® thermal analysis is recognized for a range of applications, including the characterization of hydrocarbons in solid rocks, petroleum products and sedimentary rocks. Its use to characterize the nature of Soil Organic Matter (SOM) is also being developed, particularly for agronomic and environmental purposes. In this context, the originality of this study consists in using Rock-Eval® to explore its potential to characterize the nature of organic matters (in this experiment : silage maize, silage maize after anaerobic digestion, silage maize after pyrolysis), and then to characterize SOM after the addition of these organic matters.

The results of these characterizations are interpreted in the light of soil respiration measurements. Durability and significance of the SOC storage in soils depends on the biological decomposition/stability of organic amendments and SOM. CO_2 production measurements, during two laboratory incubations (142 and 56 days), has enabled the calculation of carbon storage resulting from the addition of organic matters. Soil respiration measurements also enabled us to trace organic matters and SOM decomposition, using ^{13}C-CO_2 as a tracer.

Throughout the incubation, CO_2 production from controls (i.e., unamended soils) were steady. Soils amended with silage maize and digested silage maize showed a higher CO_2 production than those of controls. For soils amended with pyrolyzed silage maize, CO_2 production was equal to CO_2 production from controls. SOC storage resulting digested silage maize addition was higher than silage maize addition. Pyrolyzed silage maize addition induced a storage of up to 99% of organic carbon added.

The measurement of ^{13}C-CO_2 has revealed that the greater carbon storage induced by the addition of digested silage maize compared to silage maize is primarily attributed to the lower organic matter degradability of digested silage maize. The measurement of ^{13}C-CO_2 has also highlighted a negative priming effect induced by the addition of digestate, which contributes to an increase in SOC storage.

Using the I-index of the Rock Eval® analysis, we determined that silage maize and digested silage maize decomposition mechanisms in soils resulted in the selective decomposition of biological tissues (Figure 1). Results also highlight that the use of the soil I and R -index is restricted to the study of the stability of Organic Matter (OM) and excludes carbonaceous matter such as biochar (Figure 1). This experiment gives insights on the potential use of I-index to predict C_{org} storage after the addition of organic amendments (Figure 2). This exploratory study opens up promising avenues of research for the development of agronomic and environmental quality indicators for organic amendments and SOM based on Rock-Eval® analysis.

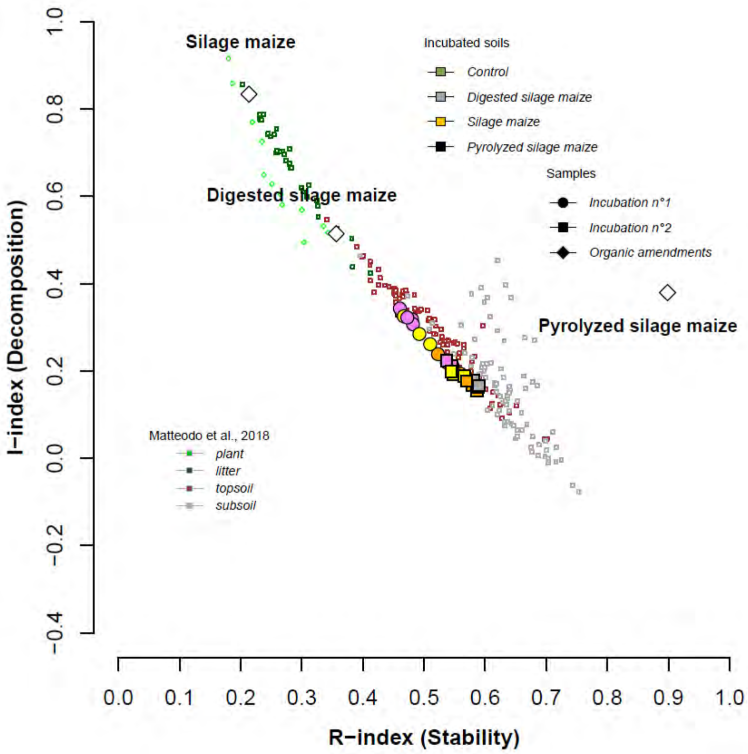

Figure 1. Positioning of organic products and incubated soils as a function of the I and R - index relative to measurements made by Matteodo et al. (2018).

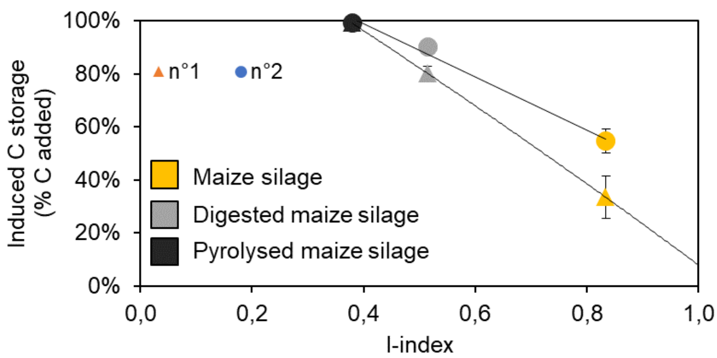

Figure 2. Correlation between C storage induced by the addition of residual organic matters (% C added) and their I -Index in soils, after incubations n°1 et 2. For the regression associated with incubation n°1, the C storage induced by pyrolyzed silage maize addition in soil is estimated by the value obtained at the end of incubation n°2.

Investigating the complementarity of thermal and physical soil organic carbon fractions in mainland France

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Assessing soil organic carbon biogeochemical stability is critical for estimating future changes in soil carbon stocks. Several methods for the assessment of soil organic carbon (SOC) biogeochemical stability have been proposed but very few can be implemented on large sample sets. Indeed, to date, only simple physical fractionation protocols (e.g. Lavallee et al., 2020) and Rock-Eval® thermal analysis techniques (Delahaie et al., 2022, SOIL discussion) have been implemented on data sets larger than a few hundred samples. Simple fractionation techniques allow separating a particulate organic carbon fraction (POC; considered labile) and an organic fraction associated with minerals (MAOC; considered more stable). Regarding thermal analyses, Rock-Eval® results associated to the $PARTY_{SOC}$ machine-learning model (Cécillon et al., 2021) provide a measure of the active (mean residence time of ca. 30 years) and centennially stable SOC fractions.

In this study, we present the results of physical fractionations performed on ca. 1000 samples and thermal analyses performed on ca. 2000 samples from French mainland topsoils (RMQS program). We compare the amount and the drivers of each fraction. Our results show that most of the MAOC fraction is not stable at a centennial timescale. However, we show using a Random Forest model that the MAOC content and the centennially stable SOC content are similarly influenced by a common set of drivers (figure): clay, pH and climatic conditions (mean annual temperature and mean annual precipitation). Finally, we discuss the complementarity of these two types of relatively high-throughput fractionation protocols.

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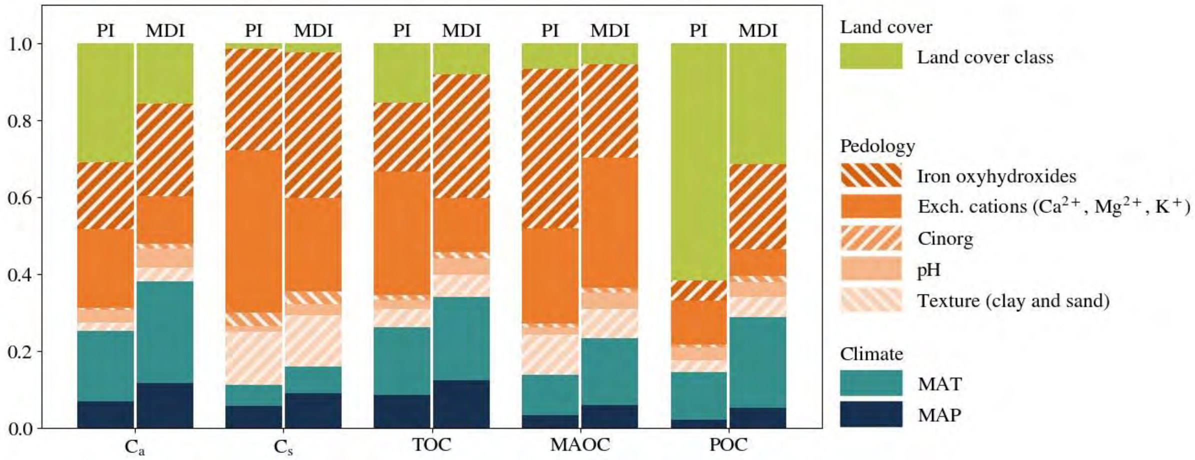

Figure: Drivers of the different fractions, determined by Random Forest modeling.

Soil Organic Carbon Storage in Moroccan Agroforestry Olive Orchards

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Abstract: Soil supports numerous ecosystem services and contributes to climate change mitigation. Several publications have appeared in recent years considering soil as a persistent carbon sink and reported that agroforestry systems have a potential for soil organic carbon storage. However, there is still little knowledge about the soil organic carbon storage in olive orchards and its role in climate change mitigation. Therefore, soil samples collected from topsoil (0-30 cm) and subsoil (30-60 cm) in 57 different olive orchards provide an excellent opportunity to investigate, for the first time, the role of several factors (tree ages, planting density, farming system type and soil depth) in driving soil organic carbon storage variability in agroforestry olive orchards compared to olive trees in monoculture system across the Saiss region (Morocco). The difference was significant between the two types of plantation systems studied (agroforestry and monoculture) and between the two soil layers studied (topsoil and subsoil). Agroforestry olive orchard systems stored approximately 1.2 times the organic carbon in the soil compared to monoculture systems. In addition, topsoil stores 1.5 times compared to subsoil. The correlation results showed that the organic carbon stock of the subsoil increases with the increase of the topsoil. These results can provide a better understanding of the effect of agroforestry on deep soil organic carbon stock in Moroccan olive orchards. Furthermore, it can provide a valuable reference for future research on the soil organic carbon storage variability in Morocco and from an international perspective.

Keywords: Soil Organic Carbon Stock, Climate Change Mitigation, Topsoil, Subsoil, Agroforestry, Olive groves, Morocco.

Session 3

THE ROLE OF BIODIVERSITY IN SOIL ORGANIC MATTER STABILISATION AND CARBON STORAGE ABILISATION OF SOIL ORGANIC MATTER: A CENTRAL PROCESS IN C-STORING AGRICULTURAL PRACTICES

Microbiome of forest soils: biodiversity, function and responses to global change

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Abstract:

Forests influence climate and mitigate global change through the storage of carbon (C) in soils. This is possible through the interplay of activities of trees – the dominant primary producers in forests and the microbiome in forest soils that have complex roles in ecosystem processes. The microbiome of forest soils consists of symbiotic fungi forming associations with tree roots (ectomycorrhiza or arbuscular mycorrhiza), saprotrophic fungi that mediate decomposition of organic matter in soil and bacteria that largely regulate the nitrogen cycling in soils. The health of the soil microbiome is partly expressed in its taxonomic and functional biodiversity that reflects the health and stability of tree stands. The intimate interplay between trees and the microbiome reflects the fact that tree-derived compounds are the major source of carbon for all soil microorganisms, received either in the form of dead plant biomass or directly through the mycorrhizal associations. As a consequence, the activity of the forest microbiome reflects the dynamics of the tree activity across the year. At present, forest ecosystems face multiple challenges associated with global change. These include increases in carbon dioxide, warming, drought and fire, pest outbreaks and nitrogen deposition. The response of forests to these changes is largely mediated by microorganisms, especially fungi and bacteria. The effects of global change differ among boreal, temperate and tropical forests. The future of forests depends mostly on the performance and balance of fungal symbiotic guilds, saprotrophic fungi and bacteria, and fungal plant pathogens. Drought severely weakens forest resilience, as it triggers adverse processes such as pathogen outbreaks and fires that impact the microbial and forest performance for carbon storage and nutrient turnover. Nitrogen deposition also substantially affects forest microbial processes, with a pronounced effect in the temperate zone. The understanding of plant–microorganism interactions helps to predict the future of forests and identify management strategies to increase biodiversity, ecosystem stability, C storage and mitigation of the greenhouse gas production.

The role of soil fauna on soil organic matter storage depends on organic matter interaction with mineral matrix but not only on that.

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Globally across all biomes, soil fauna consumes more than half of annual litter fall and this proportion is even higher in temperate zone. Majority of consumed litter turn into fauna feces, which can either accumulate on soil surface or become incorporated in soil by bioturbation. Here field mesocosms (size?) that were either accessible or inaccessible to soil fauna were used to quantify the effect of soil fauna on C storage in mineral soil. In total how many? mesocosms were exposed in 23 locations covering all climatic zones around the world (mostly northern hemisphere). Results show that fauna increased incorporation and storage of C in mineral soil by fauna bioturbation. In comparison with previous metanalysis of litter consumption by soil fauna it can be estimated that about half of litter consumed by fauna is incorporated in soil and remained in mineral soil. Fauna mediated increase in organic matter incorporation in mineral soil layer increased with increasing actual evapotranspiration of the sites and decreasing C/N ratio of litter. Laboratory experiments show that most of the litter C incorporated in soil appear in form of particulate organic matter (POM) or POM occluded by mineral particles. Occlusion slows down its decomposition and may promote formation of microbial necromass.

Moreover, our experiments and extensive metanalysis show that, in comparison to litter, decomposition slows down even in fauna feces that accumulate on soil surface without direct contact with soil. Several mechanisms responsible for this decomposition slowdown in these holoorganic fauna feces was proposed and experimentally tested. Compare to litter in fauna feces easily decomposable substances has been removed, which not only reduce their decomposition but also priming effect litter addition may have. Priming effect is further reduced by fact that leachate from fauna feces has low CN ratio and causes negative priming effect compare to leachate from litter that cause positive effect. Nitrogen in holoorganic fauna feces gets less accessible due to binding of proteins and amino acids in insoluble complexes with phenolics. Fauna promote microbial growth, but also kill and digest microbes in its gut. The alternating promotion of microbial growth and killing and digestion of microbes may support accumulation of microbial biomass.

Soil macro invertebrates enhance C storage in tropical soils following application of the FBO technology

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We evaluated the potential of the FBO (Fertilisation Bio Organique ®) technology to store carbon provided in the form of organic fertilizer in a Colombian plantain banana plantation. FBO is a nucleation technique which consists in planting perennial plants in 1.0 x 0.4 x 0.4 m deep trenches where low- and high-quality organic materials are added in a specific design and endogeic earthworms are inoculated. In the experimental setup, the two sources of organic materials were either separated (T1) or mixed (T2). We postulated that earthworm feeding activities would stimulate cast production, with casts likely to be further stabilized as large soil macro aggregates, within which organic matter would be physically protected from decomposition and mineralization. Total macroinvertebrate population densities increased more than twofold between the control and the FBO treatments, with especially high increases in populations of Isopoda (+493 to + 762%), Diplopoda (+698 to +877%) and endogeic earthworms (+457 to +622%). Soil macro aggregation was greatly enhanced in the FBO treatments with spectacular increases in the percentages of large >1cm (+48.2%), medium 0.5 to 1 cm (+65.7%), and small < 0.5 cm (+212.5%) biogenic macro aggregates at expenses of the physical aggregates and residual soils that were almost absent. The organic matter content of aggregates was lowest in physical and large biogenic aggregates, intermediate in medium sized macro aggregates and maximal in residual soils and small macro aggregates. Depth and treatments also affected marginally these values. On a hectare scale and to a depth of 30 cm, the organic matter stored in the FBO treatments represented between 1.07 and 4.5‰ of the total initial stock of organic matter. Respirometric activity declined by half in the large and medium sized macro aggregates compared with the residual soil. Our results illustrate the substantial effect of macroinvertebrate activities on the progressive incorporation of organic residues into a succession of macro aggregate structures, within which they are significantly protected from mineralization.

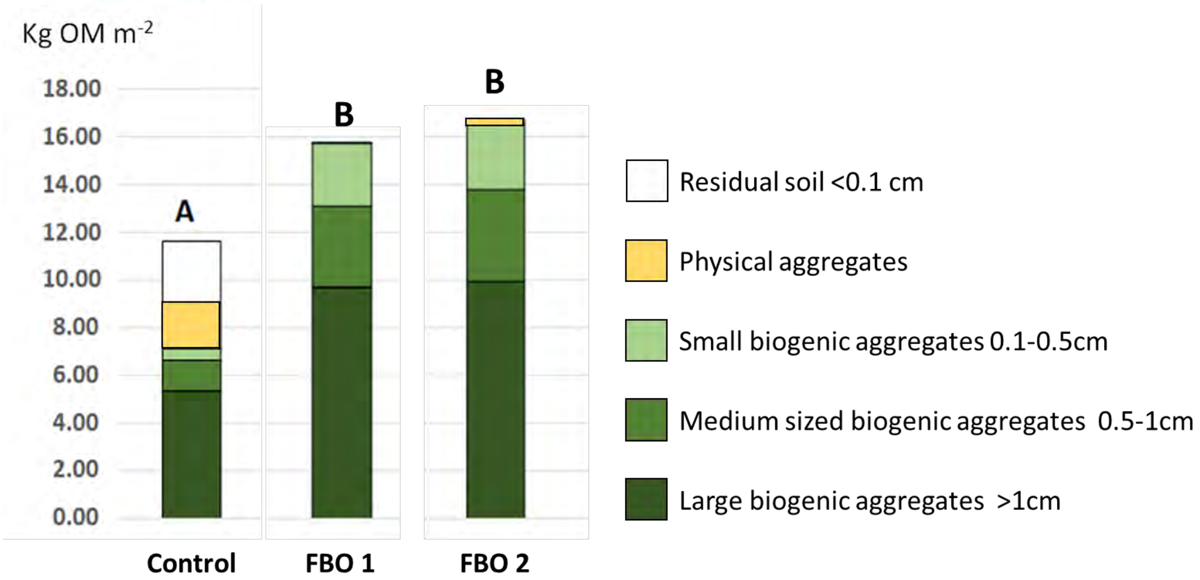

FIGURE 1: Accumulation of organic matter in macro aggregated fractions and residual soil (kg m^{-2}) in control and the two FBO treatments.

The French Program FairCarboN

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To meet the goal of limiting global temperature rise to less than +1.5°C by 2050 (Paris Climate Agreement), the achievement of global carbon (C) neutrality is critical. This cannot be achieved without significant advances in our understanding of carbon (C) dynamics in terrestrial ecosystems. There is an urgent need for progress in understanding the determinants of C dynamics and for the development of credible scenarios of changes in land use and land management practices. Such research must simultaneously take into account both socio-economic (e.g., public policies, C prices, circular economy) and biophysical (e.g., water and nutrient resources, ecosystem capacities for increasing perennial biomass and C stocks) determinants and identify possible synergies or antagonisms between different actions. The French program "FairCarboN" aims to i) quantify the contributions of continental ecosystems to the evolution of C flows at different spatio-temporal scales and in the context of global change, and ii) to use these data to propose management strategies that can inform public policies and stakeholder decisions. FairCarboN has three main objectives: (1) to remove barriers to knowledge regarding the key processes governing the C cycle and their responses to global change; (2) to provide the scientific community and relevant stakeholders with validated numerical models that can be used to simulate changes in ecosystem C stocks at different scales (local, territory, global); and (3) to develop, test, and evaluate, in cooperation with various partners (members of the general public, NGOs, public policy makers, etc.), different scenarios of change and their impact on the environment, along with data to support their implementation at the territorial and national scales. FairCarboN will capitalize on the dynamism of the French scientific community, spread across different institutions and recognized internationally, as well as on the strengths of research facilities in mainland France, overseas territories, and internationally, particularly in the Global South. Its goal is to raise France's scientific leadership to the highest level in this strategic area, and to provide expertise and support for French public policies by actively soliciting the contributions of stakeholders. This ambitious program (2023-2028) will mobilize a large community of scientific experts toward understanding the potential contributions of continental ecosystems to climate change mitigation, without which the objective of the Paris Agreement is not achievable.

Influence of intra- and inter-specific plant biodiversity on soil functioning: soil response under the use of Evolutionary Populations in a rotation system

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Abstract:

Intense conventional crop production is characterized by a large use of inputs and are systems inducing a strong pressure on the environment through biodiversity loss or soil degradation. Moreover, climate change combined with the rise of extreme climatic events threaten crops yields. Therefore, there is a need to adopt sustainable agricultural practices that could reduce the agricultural impacts on the environment while enhancing its resilience.

Evolutionary Populations (EP) are plant populations presenting a high degree of within crop genetic diversity that usually show a lower input need than Mono-variety crops. As well, they often exhibit a higher buffering capacity in response to environmental stresses. They could be used as alternatives in areas where cultivation can be difficult such as in Mediterranean areas. An important aspect of the adaptation of EP in those environments remains in the relationship between root systems and soil microorganisms. The aim of this work is thus to investigate if EP crops lead to contrasting soil functioning.

We carried out a field experiment including conventional and evolutionary populations of wheat to investigate their effect on soil functioning. We aimed to understand if (1) EP can participate at modifying soil organic matter composition, (2) if they can participate at modulating soil microbial communities and (3) their activities. To this end, we analyzed soil MIRS signatures as well as microbial communities through EL-FAME extraction while assessing soil enzyme activities. We characterized bulk and rhizosphere soils from EP and conventional wheat after precessions of legumes or wheat at two Italian sites.

Our results highlighted that, after a year of cultivation, EP did not disturb soil microbial communities or their activities and neither modified soil organic matter composition. Co-inertia analysis demonstrated that soil organic matter was more correlated to enzymes activities than to microbial communities. Nevertheless, observed results were highly dependent on the sites and the type of rotation. Those results have to be investigated in a longer-term way and a monitoring of these crop systems on several years will be performed.

RHIZODEPOSITION PLANT-PROPERTIES AND PREVIOUS LAND-USE CONTROL BOTH MICROBIAL COMMUNITIES AND SOIL CARBON ADDITIONNAL STORAGE

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Soil carbon storage can both mitigate climate change while enhancing food security. A recent study identified that pearl millet lines with large rhizosheath of root adhering soil contribute significantly to increased carbon supply into soil compared to pearl millet lines with small rhizosheath (Ndour et al. 2022). The aim of this work is to compare the effects on rhizospheric microbiota and soil carbon storage for two millet lines with contrasting rhizodeposition properties and for two soils with significantly different initial carbon content.
We grew two lines (L220 and L132, Ndour et al. 2017) of pearl millet on a 28-day growth cycle in a Mediterranean arenosol under different previous land-use: vineyard (carbon poor) and forest (carbon rich) (Quéro et al. 2022). We conducted metabarcoding analyses to characterize the microbiota in roots, root-adhering soil, and unplanted soil. Additionally, soil organic carbon content was quantified using elemental analysis across various compartments: root-adhering soil, rhizosphere (non-root-adhering soil), and control unplanted soil.
The rhizosphere effect is illustrated by the decreasing trend of alpha diversity across compartments for both soils: unplanted soil > root-adhering soil > roots. Additionally, the carbon content increased following the ranking: root-adhering soil > not root-adhering soil > unplanted soil. However, the land-use has a great impact on both carbon gain and microbial communities. Notably, the carbon gain is more than 4-fold greater in root-adhering soil already rich in carbon (forest soil) compared to vineyard one. At the same time, there were significant variations in microbial composition as a function of land-use. These unexpected result will be presented and thoroughly discussed from a soil carbon storage perspective.

*This work received support from the French government under the France 2030 investment plan, as part of the Initiative d'Excellence d'Aix-Marseille Université - A*MIDEX (AMX-19-IET-012).*

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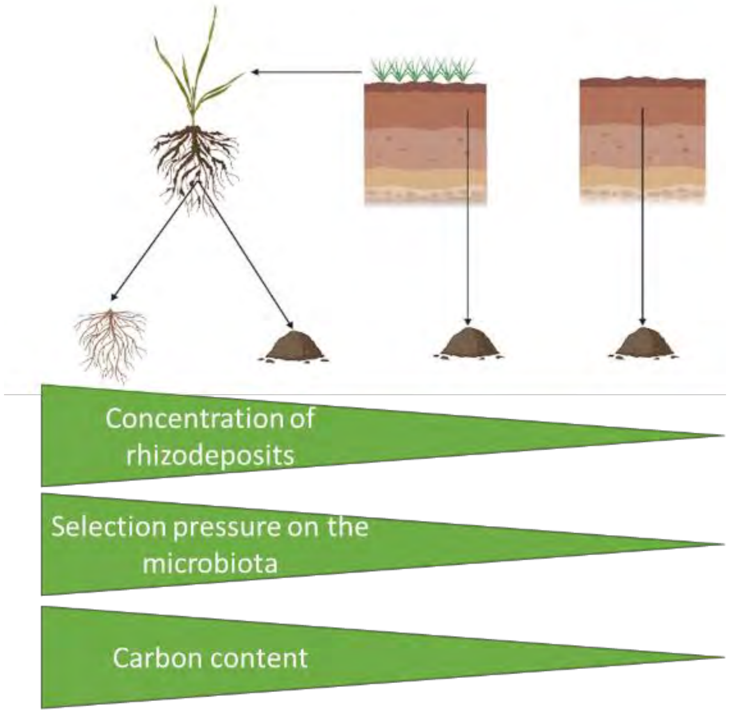
Concentration of rhizodeposits
Selection pressure on the microbiota
Carbon content

Follow-up (stable isotope) of rhizodeposition and litter in soil micro-arthropods under 15 grassland species with contrasting strategies

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Understanding soil fauna's role in biogeochemical cycling is of utmost importance in the context of global change. Plant-fauna interactions are a crucial component of organic matter decomposition processes, especially via regulation of microbial populations. However, we still lack knowledge of their relationships with plant acquisition strategies, whose links with biogeochemical cycling are well documented.
The theoretical framework of the "plant economic space" (PES) describes two strategical trade-offs associated with resource allocation: (i) rapid growth sustained by wide exploration and large nutrient uptake opposed to slow growth with limited nutrient absorption and (ii) investment in a plant's own foraging system opposed to externalization to mycorrhizal fungi. Resource acquisition strategy determines quantity, quality and localization of two essential organic matter sources in soil: litter and rhizodeposition. Direct or indirect (via saprotrophic fungi or plant-associated micro-organisms) dependance of micro-arthropods, a major soil fauna group, to these two resources is partially documented. A better understanding of the complex trophic links of these organisms to plant strategies would allow us to better integrate them in biogeochemical cycling models. These issues are particularly interesting with the recent paradigm shift suggesting that stable organic matter is mostly formed from living plant-derived small molecules associated with minerals, not only from complex compounds obtained from recalcitrant litter.
We here studied the relationship between several functional groups of micro-arthropods and these basal resources thanks to an experiment with 15 grassland species with contrasting strategies. To do so, we grew these 15 grassland species in a 3-month pot experiment, with or without litter inputs. By means of isotope labelling, we traced nitrogen (N) fluxes from litter decomposition and carbon (C) fluxes from rhizodeposition in different pools, including microbial biomass, soil organic matter, soil respiration and micro-arthropods.
We expect some functional groups to rely more on one type of resource, and that overall, biomass of micro-arthropods depends most on the availability of organic matter.

Improving the simulation of CO_2 fluxes integrating microbial biodiversity into a simple soil organic carbon model

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Numerous models have been developed to simulate and predict the dynamics of soil organic carbon (SOC) stocks and greenhouse gas (GHG) fluxes at site and regional scales.
While 'classical' SOC models typically assume first-order kinetics to describe the decomposition patterns of conceptual SOC pools, there has been a recent shift towards incorporating microbial activity due to its significant role in SOC decomposition. However, microbial explicit SOC models usually treat microbial biomass as a single pool, although microbial diversity is understood as a crucial predictor of SOC respiration. In fact, kinetic parameters of different microbial communities are poorly constrained, and representing diversity likely adds too much complexity for large-scale model simulations.
In this study, we incorporate a simple rate modifier to capture the influence of microbial functional diversity on SOC decomposition, into a state-of-the-art SOC model. The aim is to assess whether microbial functional diversity is a determining factor for capturing the dynamics of CO_2 emissions in a forest site following a disturbance event (e.g., cutting and logging) that reduced microbial diversity and altered the soil environmental conditions. To achieve this, we rely on standard rate modifiers to account for changes in environmental conditions and we integrate the microbial diversity rate modifier to account for microbial community changes. With this new model parameterization, we then compare the simulated CO_2 dynamics to the default model simulations without diversity effects.
Finally, we discuss whether the inclusion of the simple rate modifier dependent on microbial functional diversity enhances the ability of the linear kinetics model to depict CO_2 dynamics in the aftermath of a disturbance event, without adding complexity to the model structure.

Session 3

ABSTRACTS of POSTERS

Unveiling the Potential of Soil Prebiotics: Indigenous Microbial Recruitment for Enhanced Soil Health, Plant Growth, and Carbon Sequestration

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In the context of population growth, climatic change, and environmental concerns, soil management emerge as a pivotal tool for addressing these challenges. To preserve and restore soil fertility and productivity, various innovative agroecological solutions are being explored. Among these, prebiotics stand out as a type of soil biostimulants applied to enhance soil quality, promote plant growth, and potentially improve carbon (C) sequestration. In this aspect, our study was designed to assess and elucidate the effects of two commercial prebiotics, K1® and NUTRIGEO L® (SPK and SPN). The application of these prebiotics, combined with organic wheat straws, resulted in positive effects on both soil fertility and plant growth, surpassing the outcomes of the control (SP). Notably, after 10 weeks of application (D2), these biostimulants led to significant increases in plant biomass, particularly in the roots. This effect is attributed to the enhancement of soil characteristics and the modulation of native microbial communities. With respect to soil characteristics, both prebiotics showed a significant increase in electrical conductivity, cation exchange capacity, and phosphorus availability at D2, while SPN elevated several minerals, such as calcium, boron, and iron. These cationic soil minerals play an important role in the C cycle, sorption of dissolved organic carbon (OC), and organic matter (OM) stability. Regarding soil microbiota, each prebiotic induced a unique shift in the bacterial and, to a greater extent, fungal community structure and diversity, notably at D2. Moreover, we observed the recruitment of a diverse consortium of beneficial native microorganisms (including saprophytic, endophytic, symbiotic, endohyphal, and plant growth promoting taxa) by each prebiotic, contributing to their unique ecological services. For instance, bacteria such as *Caulobacter*, *Sphingobium*, and *Massilia* as well as fungi such as *Mortierella globalpina* and *Schizothecium carpinicola* were identified in SPK. On the other hand, bacteria such as *Chitinophaga*, *Neobacillus*, and *Rhizomicrobium* along with fungi such as *Sordariomycetes* and *Mortierella minutissima* were associated with SPN. These prebiotic treatments, especially SPN, significantly increased plant root mycorrhization and correlated soil proteins (glomalin). The overall effects of the SPN treatment on soil physicochemical and microbial aspects distinguished it with its ability to augment soil OM and total C content, thereby promoting C sequestration. In order to better understand and explain these prebiotics' effects and modes of action, further studies will be conducted to identify and assess their active and passive components and their intricate interactions. These comprehensive findings revealed the potential of prebiotics, shedding light on a novel eco-conscious benefit that can be harnessed through their application: C storage. This newly uncovered service offers a promising tool in the arsenal of climate change mitigation strategies, countering soil exploitation and degradation, the continuous increase in C emissions, and its threatening accumulation in the atmosphere. Our objective is to affirm the pivotal role that prebiotics can play as a new alternative in the agroecological transition towards a modern, resilient, and sustainable agriculture.

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The role of plant functional group diversity on soil carbon cycling processes in a simple model soil

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Abstract:

The transformation process of plant biomass into soil organic carbon (SOC) is driven by soil microorganisms. Meanwhile particulate organic matter derived from plants shape the belowground microbial communities and influences their activity and growth. Understanding how microorganisms converge labile plant compounds into more persistent soil organic matter is central to foster our knowledge about the terrestrial C-cycling. Microbial carbon use efficiency (CUE) represents an informative parameter as it captures the efficiency at which carbon is incorporated into new microbial biomass. Plant diversity seems to play a crucial role when it comes to carbon storage in soils, as previous studies showed that increasing plant diversity was associated with higher carbon stocks. While those previous studies showed that plant diversity is associated to higher SOC stocks, we still lack in understanding the role of distinct plant functional types and their combinations in driving soil C cycling. This study is based on a laboratory incubation experiment, that focuses on the mechanisms influencing the microbial-derived SOC formation and its persistence in soils. Above and below ground biomass from distinct plant functional types (N fixers and no N fixers, deep rooting- and shallow rooting plants, composed of eight plant species) and their combinations were added to a model soil and inoculated with a microbial community extracted from an agricultural soil. Their decomposition through time is being evaluated. We hypothesize that different qualities of plant biomass influence microbial communities regarding their activity and composition. We further hypothesize that the molecular diversity of different kinds of plant material added to the model soil are expected to affect the composition and persistence of SOC. In this ongoing decomposition experiment, we analyze at different points in time the plant phytochemical signature, the soil microbial community composition and diversity, the cumulative respiration, CUE, the thermal-stability and composition of SOM. Contrary to the hypothesis, our first results show that respiration rates were higher in soils with a more diverse combination of plant functional groups compared to the ones with a lower level of diversity. Our following up measurements will help us better understanding how plant functional groups influence soil C-cycling.

Impact of the molecular structure and microbial community features on the stability of organic components in soil

Senta Heiss-Blanquet, Simon Poirier, Violaine Lamoureux-Var, Véronique Bardin, Herman Ravelojaona, Ambre Tafit and David Sebag

The persistence of soil organic carbon (SOC) depends on various bio-physico-geochemical factors, such as physico-chemical soil properties, the complexation by mineral compounds, microbial diversity and the complexity of organic matter. However, the relative impact of these factors on SOC stability is insufficiently understood, not least because determining the organic matter stability remains a major challenge. In the present study, we therefore evaluated the intrinsic stability of various organic compounds in different soils harboring distinct microbial communities using biological and thermal approaches.

Two forest soils and one grassland soil were incubated with organic molecules representative of microbial and plant biomass found in soils, such as cellulose, aromatic nitrogen-containing compounds, fatty acids and lignin. The kinetics of aerobic microbial degradation were monitored in parallel to the thermal stability of the respective compounds using a Rock-Eval® ramped thermal analysis. In addition, the evolution of the composition and the abundance of bacterial and fungal communities were assessed by metabarcoding and qPCR.

Results show that the extent of biological mineralization was generally inversely correlated to the final organic matter and stable organic carbon contents as determined by Rock-Eval® parameters. Furthermore, soil structure and microbial community composition led to a differential response as a function of soil type for some of the substrates tested, in particular cellulose, cutin/suberin-derived compounds and aromatic nitrogen-containing compounds. Forest soils show a more similar response to substrate addition, in terms of degradation capacity, fungal and bacterial diversity. On the contrary, grassland soil displayed distinct diversity profiles which might be related to its lower capacity of nitrogen-containing aromatic compound degradation and its higher capacity to degrade some aliphatic compounds compared to forest soils. In summary, we could show that the composition of organic matter contributes to its biological stability in soil and that it is linked to thermal stability, but that other factors such as microbial community composition can modulate this feature.

Characterizing stability and dynamics of organic matter in worm compost using Rock-Eval® analysis - preliminary results

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Numerous questions are pending on the role of soil engineers on the organic matter evolution in soil and more generally on the complete biochemical cycle of the carbon. Worm compost, used to enrich the soil with organic compounds, improves soil structure and fertility. As a characteristic product of soil engineers, it is then of high interest to study.

Rock-Eval® thermal analysis allows to quantify the C-H bonds in the organic matter (OM) of a sample through controlled open-pyrolysis. Relying on the hypothesis that thermal stability can serve as a proxy for biogeochemical stability, such analysis is nowadays commonly used to characterize OM in soils (Sebag et al. 2006; Albrecht et al. 2015; Sebag et al. 2016) or to assess the impact of worms on organic matter (Ducasse et al. 2023) both at a field and meso-scales (such as a flowerpot). However, no experimental study exists using a commercial worm composter. In many commercially available worm composters, the trays are periodically rotated downward over the composting time. This action raises the question of whether it is possible to track the temporal evolution of the organic matter extracted from these trays. To answer this question, the aim of our work was to carry out an initial sensitivity test to determine whether the Rock-Eval® signatures of the samples taken are consistent with past work.

We here found that the standard and advanced parameters obtained in Rock-Eval® thermal analysis were consistent with those obtained in natural litter and in the field. In particular, we clearly identified the decomposition of the most labile materials over the composting time (see Fig. 1) and we matched the signature interval of forest humus in the (I,R) diagram with I ∊ [0.1 ; 0.5] (Sebag et al. 2016).

The conclusions drawn from this initial feasibility study are that it is possible to use this type of worm composter as a model system for studying the impact of earthworms on organic matter thanks to the possibility of isolating the castings over the composting time.

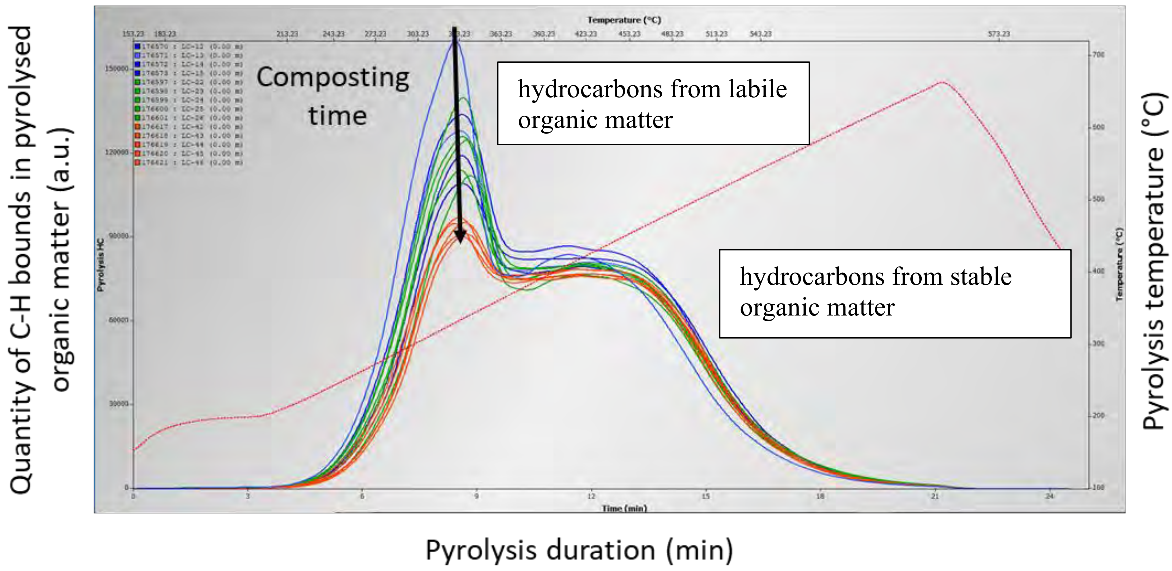

Figure 1: Evolution of the quantity of C-H bounds in pyrolyzed organic matter in casts as a function of composting time.
Sampling was done monthly: blue = sampling month #1; green = sampling month #2; orange = sampling month #3. Reproducibility was obtained based on five replicates. It is shown that hydrocarbon labile compounds significantly decrease on the three months composting duration, while more refractant HC compounds evolve much less on the same period of time.

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Monitoring carbon stocks in arable land: sources of errors, improvement of the one-layer equivalent soil mass method and minimum detectable change

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Reliable determination of the soil organic carbon (SOC) stock (SOCS) and its time trend at field scale is a key condition to monitor the agro-ecological transition, to evaluate the effectiveness of climate mitigation plans, or to value soil organic carbon (SOC) sequestration as a negative emission technology (NET) at farm level. Limiting the SOCS estimation to 30 cm depth is acceptable on the range of some decades (Balesdent et al., 2018). SOC stock, however, is not directly estimated from the SOC content. SOC content must be multiplied by the bulk density (BD) of the corresponding layer. BD determination is time consuming and tedious to determine. Moreover, it changes with time due to soil swelling with water, soil tillage, and changes in SOC. Therefore, the changes in SOCS must be monitored on an equivalent soil mass (ESM) basis, by referring to the sampled soil mass of the previous sampling rather than to a constant depth layer. Corrections of the mass, simplification of the soil mass determination overcoming the BD determination issue, as well as a simplified one-layer method have been proposed (Wendt and Hauser, 2013). However, this simplified ESM method requires the sampling and analysis of at least two layers for sampled mass correction and large unknowns remain on the sources of errors. For instance, the field volume percentage of the coarse (> 2 mm) fraction must be determined and removed from the sampled layer volume, which is not well documented. On the other hand, and to our best knowledge, private companies providing a SOCS certification use to sample the soils at constant depth using mechanical gauges that do not allow control of the quality of the extracted cores. The errors associated with these different technical options need to be clarified.
This study was performed by sampling 384 representative fields from different farms of the Swiss Leman-Lake region. It aimed at providing a full reliable methodology to determine SOCS at field scale, while solving the remaining issues, namely, to determine the errors associated to the different parameters estimated and to simplify the ESM one-layer method to decrease the sampling and analytical costs. Comparing mechanical and hand-held gauges showed that only the latter performed reasonably for SOCS stock evaluation. The minimum detectable change was then determined (i) for sampling performed at constant depth, (ii) for the ESM one-layer method as described in (Wendt and Hauser, 2013), (iii) the additional error introduced by coarse fraction estimation and gauge diameter and (iv) a simplification of the one-layer ESM method taking into account local average properties of the soil below the 0-30 cm sampled layer.
We conclude that the classical constant depth automatic sampling cannot be used for SOCS monitoring, while the proposed simplified one-layer ESM method yields acceptable minimum detectable changes allowing to detect most changes in a 5 to 10 year time lag in Swiss arable land at a much lower cost.

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Role of time and cover crop on soil chemico-physical traits in an olive orchard in a semiarid area

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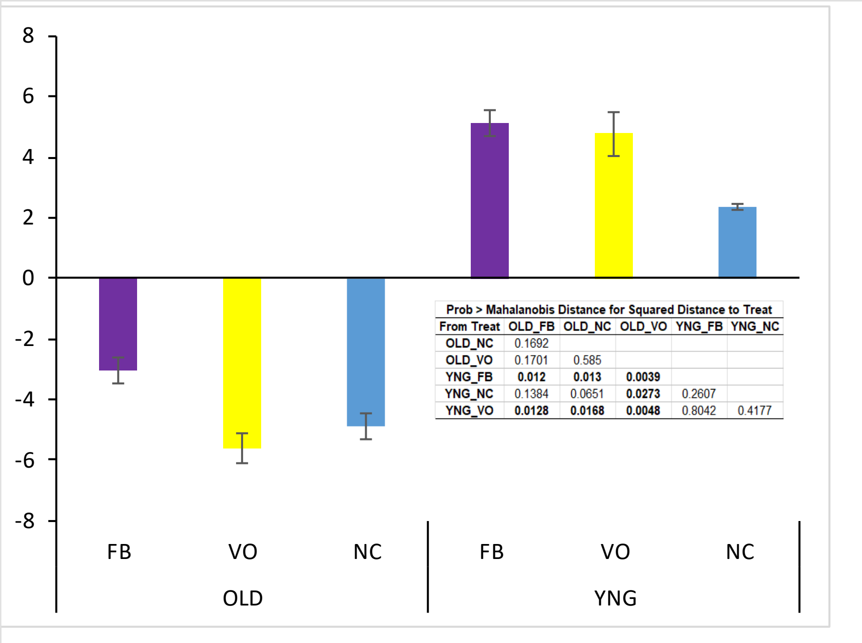
ABSTRACT

Olive orchards in semiarid areas are usually kept with bare soil, with harmful effect on soil. This study digged into the role of age of the orchard (ORC_AGE) and Cropping System (Crop_sys) based on cover crop (CC) on Soil Organic Carbon (SOC), Bulk Density, and other soil traits in a semi-arid region of Tunisia. ORC_AGE consisted in a mature and a young olive orchards (aged 50 and 15 years, respectively), both subjected to tillage. Crop_sys consisted in 3 contrasting CC treatments (faba bean [FB] CC, vetch-oat [VO] intercrop CC, and bare soil [NC] as a control). Samples were taken below the olive canopy from the 0-10 cm layer. The experimental design was a split plot with ORC_AGE as a main plot. Non-correlated variables at $|r| > 0.7$ were selected, standardized, and included in a canonical discriminant analysis (CDA, SAS/STAT 9.4) to capture the multivariate effect of treatments on the experiment variability and relationship among variables. Differences by the treatments and interaction on each variable were checked by a general linear mixed model (SAS/STAT 9.4). Few correlations were found (data not shown). A negative correlation was found between SOC and BD ($r=-0.98$). This may have been due to a lower soil mass sampled in the sampling points with lower BD, which can directly affect the SOC estimation, as reported by Vandenbygaart & Angers (Can. J Soil Sci 2006. 86(3): 465-471) and Baldock and Grundy (Proc. GSOC, FAO 2017: 35-41). The treatments showed unclear effects on most of variables, including soil texture, with the exception of $CaCO_3$, Ca and P, which were 85.2%, 9.4%, and 92.4% higher in the old than the young orchard. These differences may be due to a potential soil transport through erosion, despite the P concentration may have been also due to unaccounted fertilization applications. The CDA yielded on significant explanatory variable (Figure 1) explaining 80.9% of the total variability, and showed that the ORC_AGE was a main discriminant of the whole variability. So far, Crop_sys showed a distinctive pattern within ORC_AGE: the young-NC orchard could not be distinguished from both the old NC and FB orchards. Lastly, the CDA unveiled similar behaviours of P, Mg, and Ca from the one side, and SOC, EC, and pH from the other side (Figure 2), which may be related to fertilization, and a short term effect of the cover crop, respectively. In conclusion, it is noteworthy that SOC did not vary between orchards, despite a long term tillage operation in both plots, and the CC had a minimal effect on the variables.



Prob > Mahalanobis Distance for Squared Distance to Treat					
From Treat	**OLD_FB**	**OLD_NC**	**OLD_VO**	**YNG_FB**	**YNG_NC**
OLD_NC	0.1692				
OLD_VO	0.1701	0.585			
YNG_FB	**0.012**	**0.013**	**0.0039**		
YNG_NC	0.1384	0.0651	**0.0273**	0.2607	
YNG_VO	**0.0128**	**0.0168**	**0.0048**	0.8042	0.4177

Figure 1. Projection of treatments on the CA1. In the nested table, the p test of the treatment distance compared to the Mahalanobis distance

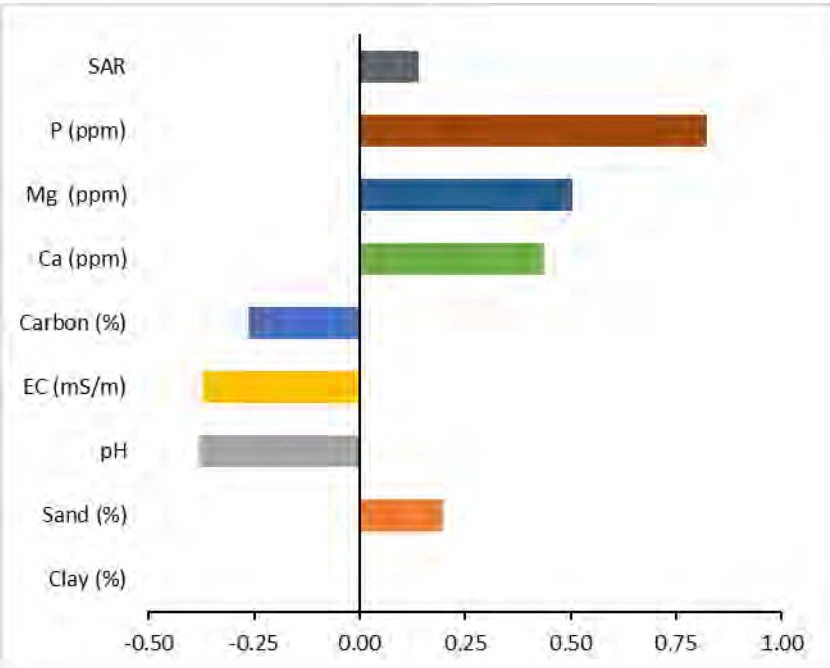


Figure 2. Correlation between each variable and the CA1

Session 4

MICROBIOLOGICAL, GEOCHEMICAL AND MATTER TRANSFER INTERACTIONS: AN INTEGRATED APPROACH

Physical protection of organic matter: a biophysical model

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Soils contain the largest terrestrial reservoir of organic carbon, and dynamics in soil organic matter (SOM) turnover will drive carbon-climate feedback over the coming century. To date, most SOM dynamics have been simulated with pool-based models, rather than explicit considering accessibility. These models have substantially advanced our understanding of soil organic matter dynamics, informed decision making and soil management. However, questions need to be asked if capturing physical protection this way reflects our increased understanding of the microscale environments in soils. An alternative way to look at accessibility is to focus on the pore geometry as the soil-phase where microbes reside, move, and gases, enzymes and dissolved organic matter diffuse. Pore geometry is a critical factor in affecting the accessibility of organic matter for microorganisms, and the challenge is to capture this accessibility explicitly in models thereby bringing more physical realism in our approach. Such an approach would allow for a process driven sliding scale of accessibility. We will demonstrate how such an approach can be developed and exemplify this for fungal mediated breakdown of SOM. First, we will empirically test how pore geometry affects fungal spread, and how this can lead to threshold like behaviour or tipping points. We will then capture this in a spatial explicit model and apply this to a 3-dimensional soil environment. As we gradually enhance the complexity of the soil environment, we will redefine pore accessibility as we seek to relate pore-connectivity on organic matter turn-over. For a complex system the question of what constitutes accessibility is not easy to address and needs to consider more than the pore sizes and exclusion. For example, for fungal mediated processes, accessibility may be determined by various characteristics, namely: (i) the total volume of the connected pore space; (ii) the connected air-filled pore volume, through which fungal spread predominantly occurs and gasses diffuse, (iii) the connected water phase volume, through which dissolved C diffuses, (iv) the distribution of particulate organic matter that fuels fungal growth, and (v) biological traits such as those enabling translocation through for example fungal hyphal networks. When we consider these various processes that have impact on SOM degradation we find the following: i) connectivity of the water phase is critical as it regulates diffusion of dissolved organic matter; this is even so for fungi that preferentially spread through air-filled pores, and ii) whether fungi behave as R or K strategists is not just determined by fungal traits but to a large extend depends on the physical environment. Consequently, selective pressures can be exerted by physical conditions. It was not possible to identify a key physical driver as the dynamics were mostly determined by interactions between the various types of connectivity. These different pathways tend to compensate each other, enhancing stability of the process against environmental variability. We argue that when multiple connected pathways underpin a soil function this leads to resilience of soils to perturbations and are that connectivity and interactions are key drivers of soil health.

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Modelling soil moisture control on soil organic carbon decomposition and land-atmosphere carbon fluxes in a global scale ecosystem model

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Abstract:

Soil moisture (SM) controlled by climate and soil porosity influences spatial distribution and movability of soil organisms and of soluble gases and compounds such as nutrients, minerals and organic matter which in the end, rules soil organic carbon (SOC) stability. Indeed, these biophysical drivers, together with soil temperature, control respiration of heterotrophic organisms which lead to SOC decomposition. In global scale process-based models, these processes are formulated using functions that modify the rate of SOC decay by heterotrophic respiration (SHR) and impact global SOC stock estimated by ecosystem models. A large diversity of SHR modifiers is employed however in each model a unique relationship considering SM serves to adjust the rate of decomposition for all the ecosystems. From a meta-analysis of soil moisture content and soil physical properties emerged an empirical model representing the relationship of SM and SHR. The uniqueness of this empirical model is to reflect spatial heterogeneity of the control of SM on SHR by providing a collection of different relationship based on soil organic carbon content, clay fraction and bulk density.

In the present study, we implemented this empirical model in the ecosystems model ORCHIDEE and assessed the effect of the multivariate approach on SOC stock and SHR estimations at global scale. Results show that the empirical SM modifier enable to double SOC stock in the model while CO2 emissions due to SHR are decreased only by 25%. The latitudinal SOC distribution is maintained displaying a larger SOC stock in tropical regions than under higher latitudes.

Plant diversity drives positive microbial associations in roots enhancing carbon use efficiency in agricultural soils

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Soils are the largest and most dynamic terrestrial carbon (C) pool, storing 2000 Pg of C – more than the atmosphere and biosphere combined. However, agriculture has caused the loss of approximately 60 Pg soil C since the beginning of industrial period. Despite this, improving agricultural practices can also be used to counteract rising CO2 levels. As agroecosystems represent over 40% of earth surface today, they must be part of the solutions put in action to mitigate climate change. The utility of management practices to maximize soil carbon storage – is currently limited by a poor understanding of how plants which input carbon to soil, and the microbes which determine its fate there interact with one-another. We sampled a recently stablished plant diversity experiment (TwinWin, University of Helsinki, Finland) to evaluate the influence of ecological intensification within agroecosystems. Toward this end, barley is planted in monoculture, as well as under increasing levels of undersown plant diversity: barley plus 1 undersown species, barley plus 4 undersown species and barley plus 8 undersown species. As microbial carbon use efficiency (CUE) plays a central role in regulating the flow of carbon through soil, the overall aim of this study is to provide empirical evidence for the response of soil microbial community carbon use efficiency (CUE) to a plant diversity gradient in agricultural soils. We measured CUE with the 18O–H2O substrate-independent method, sequenced bacterial and fungal communities and determined the soil C quantity and quality. Using network analysis in combination with structural equation modeling we distinguished between the direct and indirect drivers of CUE. We observed that increasing plant diversity within agricultural soils strengthen positive interactions within the soil microbial community in relation to the negative interactions. Further, these enhanced positive interactions influenced positively microbial community carbon use efficiency. These results unveils the mechanisms by which increasing plant diversity yields higher C content in soils. Thus, suggesting that management should consider, when possible increasing biodiversity in agriculture as a strategy to enhance the potential of carbon retention in agricultural soils.

Pseudomonas brassicacearum mineral weathering activity is linked to iron homeostasis and can participate to soil organic carbon stabilization

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Interactions between organic matter and mineral surfaces have been proposed as a major driver of the soil organic carbon stabilization (Kleber et al., 2021). Recently, it has been shown that mineral weathering produces inorganic nanophases that can play a key role in stabilizing organic matter by coprecipitation (Rasmussen et al., 2018; Tamrat et al., 2019). The contribution of living organisms, including bacteria, to mineral weathering is now widely recognized (Wild et al., 2022). However, we still do not fully understand the mechanisms driving bacterial weathering, particularly the genetic regulations governing the interaction (Uroz et al., 2022).

We studied how the phytobeneficial bacterial strain *Pseudomonas brassicacearum* NFM421 (Achouak et al., 2000) interacted with biotite, a natural iron containing phyllosilicate. By constructing chromosomal mutants, we demonstrated that this bacterium increased biotite dissolution mainly through the production of two siderophores: pyoverdine and ornicorrugatine. Using molecular biology tools, we have also identified that the bacterial strains efficiently meet its iron requirements by weathering this mineral, leading to improved microbial growth. Another mechanism involving direct physical contact with the biotite allows the bacterium to get iron even if it cannot produce pyoverdine or ornicorrugatine.

As the strain is weathering biotite for nutrients, it consequently releases structural ions (silicium, aluminium and iron not absorbed by bacteria). In soil solution, these elements could interact with surrounding organic metabolites to form carbon-stabilizing coprecipitates. Understanding these mechanisms could lead to innovative agro-ecological techniques for increasing soil carbon storage and mitigating climate change.

This work received support from the French government under the France 2030 investment plan, as part of the Initiative d'Excellence d'Aix-Marseille Université - A*MIDEX (AMX-19-IET-012).

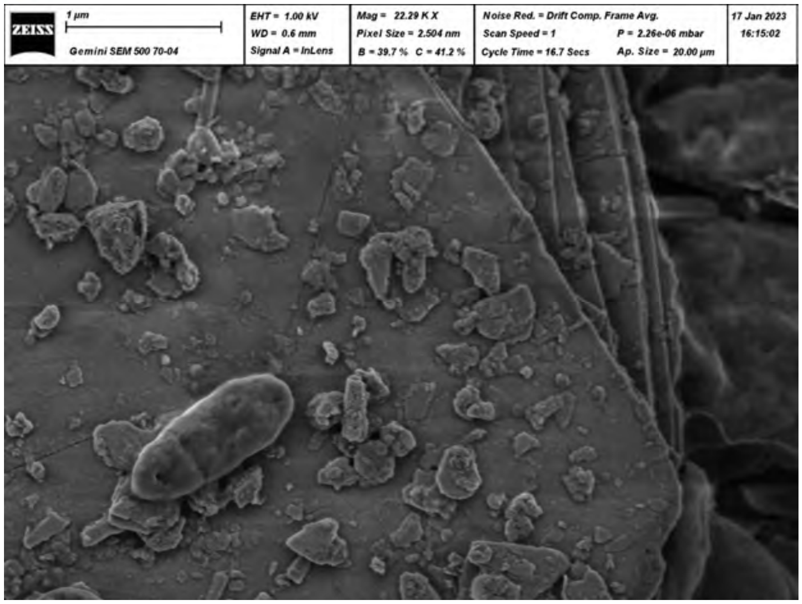

Figure 1*: Pseudomonas brassicacearum* cell on the surface of a biotite particle (Scanning Electron Microscopy, Centre Pluridisciplinaire de Microscopie électronique et de Microanalyse)

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The SHARInG-MeD project: the trade-off between Soil Health, Land Use, Soil and Crop Management from and agronomic, economic and environmental point of view in the Mediterranean Area

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The Mediterranean area is characterised by a plenty of soils, ecosystems and agro-ecosystems, and historical, and societal features, including a high anthropic pressure, which are posing hard concerns For the soil and diversity conservation and agricultural resilence. These aspects acquire further importance if considering that 25% of the global biodiversity and broad aspects of the soil functions are presently uncovered (Guerra et al. https://doi.org/10.1038/s41467-020-17688-2). At the same time, human pressure on this biome demands for an increased land use land use for agriculture, further fragmenting the habitat and reducing its resilience for biodiversity conservation. (https://doi.org/10.1126/science.abl9127). The concept idea of the SHARInG-MeD project (PRIMA 2022 GA n 2211) arose from these issues, and by taking into account that any policy measure requires models from integrated dataset built on standardized, or at least harmonized, datasets of multiple ecosystem services. In the Mediterranean areas, a standardized monitoring strategy of soil assessment is lacking. Present wide soil monitoring networks provide a starting point for an integrated assessment of the Mediterranean soils and ecosystems. These networks are namely the Land Use and Coverage Area frame Survey (LUCAS) and the Horizon 2020 Soils4Africa, which however follow different sampling strategies. In addition, LUCAS presently does not cover West Asia and North Africa, and Soils4Africa is being run only in Africa. The SHARInG-MeD will thus create a comprehensive and harmonized soil monitoring scheme, integrating physico-chemical, biological (microbes, nematodes, invertebrates, plants), agronomic, economic and environmental indicators for a better wide scale management of the Mediterranean cropland. Also, soil and plant sampling from this scheme will be conducted on paired land uses; especially agricultural uses paired with forest or grassland as a benchmark, or field and pot experiments pointing out to 2 most important and easily applicable soil-improving management practices (conservation agriculture and application of organic amendments) and the inoculation of the soil with beneficial microbes. These practices, along with the land use dimension, are crucial for the building of the soil organic carbon (SOC) fraction and reduce soil erosion, the latter of which is can strongly impair SOC accumulation (Beillouin et al. https://doi.org/10.1038/s41467-023-39338-z; Mhazo et al. https://doi.org/10.1016/j.agee.2016.04.033, Lugato et al https://doi.org/10.1126/sciadv.aau3523).

SHARInG-MeD will also integrate the information from the above-mentioned soil properties, including soil life indicators, with potential GHG emissions from the soil, and the economic fluxes and Life Cycle Assessment (LCA, including the global warming potential) in an effort to (1) harmonize various sampling schemes across the Mediterranean countries and (2) study the relationship between soil health, agriculture resilience and sustainability, (3) provide models of the relationship among the soil health, agronomic applicability of these practices, and their profit and environmental impact and thus providing indicators and tools to follow.

Land use determines the composition and stability of organic carbon in earthworm casts under tropical conditions.

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Abstract:
Environmental conditions play an important role in controlling the fate of organic carbon (OC) in earthworm casts, however, the mechanisms that lead to the destabilization of OC in different land use systems remains poorly understood. In this study, we investigated the impact of land use on the fate and composition of particulate organic matter (POM) and mineral-associated organic matter (MAOM) in earthworm casts under tropical conditions. We conducted a 400-day field exposure experiment in a woodland and meadow in northern Vietnam. Under natural rainfall conditions, this experiment compared soil aggregates without earthworm activity (reference soil) to earthworm casts. We analyzed the element content and carbon isotope and mid-infrared signatures of the two types of materials after 9 and 400 days of field exposure. The results showed that the casts were initially enriched in OC as compared to the reference soils, with the MAOM fraction accounting for over 90% of the earthworm induced OC accumulation. The POM fraction occluded in casts consisted of fresh plant material and disappeared during the 400 days of field exposure. Enrichment and composition of OC differed between woodland and meadow casts. POM and MAOM showed contrasting persistence in the two land use systems. While woodland casts showed highest potential to stabilize SOC, the actual amount of cast OC stabilized for more than 400 days was more important under meadow. Both systems showed contrasting processes affecting cast OC dynamics. Under woodland, cast OC destabilization was most probably related to microbial degradation, while in meadow, OM accumulation most probably related to root activity may be the dominant process. Our study highlights that the impact of earthworms on the origin, composition, and fate of cast OC in tropical environments is strongly influenced by land use.
Key words: Bioturbation; Land uses; Macrofauna; FTIR spectroscopy

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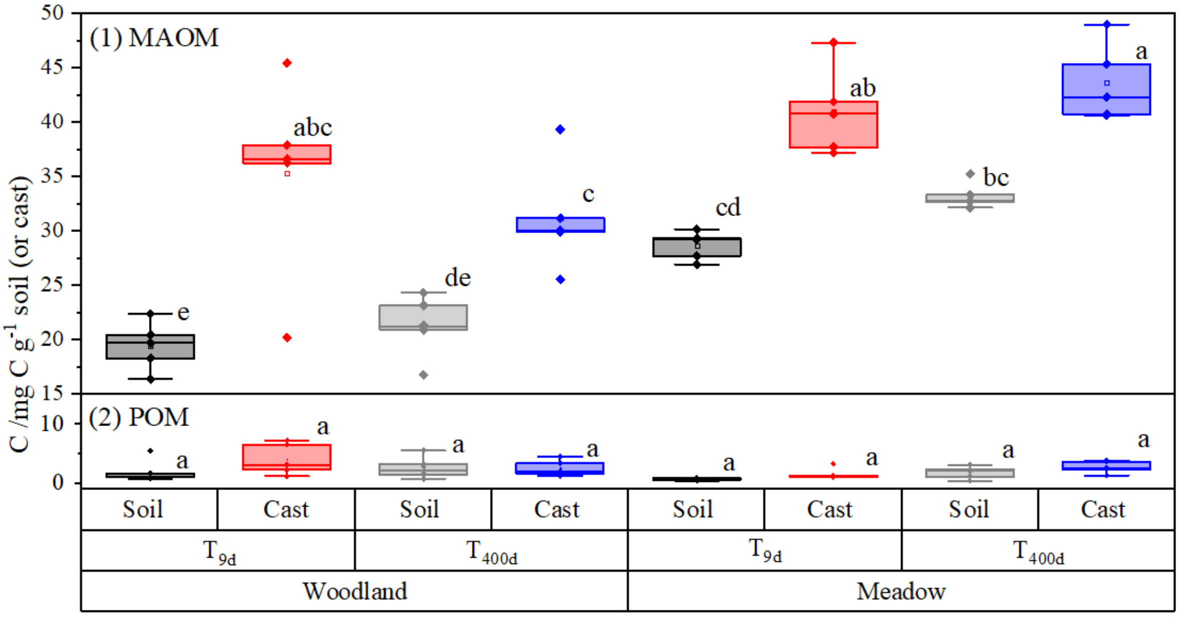

Fig. 1 The POM C and MAOM C in casts and reference soils under woodland and meadow at the two ageing stages (T_{9d} and T_{400d}). Different letters indicate statistically significant differences between casts and reference soils during ageing under different land uses (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$ and ns for $p > 0.05$, ANOVAs)

Storage of deep carbon in the Berambadi watershed (India): a comparative study between agroforestry and irrigated agriculture

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Agricultural systems face the challenge to adapt to global changes. In this context, agroforestry is increasingly seen as a way of limiting the impact of extreme events on crops, as the combined presence of deep roots and associated microbiota helps maintaining nutrients and water available to plants in the soil.
The ANR Nutrilift project aims at assessing whether the presence of deep-rooted trees in agroforestry systems has a significant effect on the functioning of the deep Critical Zone and on the biogeochemical cycles of carbon and nutrients at the scale of these agro-ecosystems. These questions were addressed with a multidisciplinary approach (geophysics, hydrology, biogeochemistry, pedology, microbiology, experimentation, modeling, etc.) in two contexts, irrigated cultivated plot (IP) and agroforestry (AF). The study site is located in the Berambadi watershed (South India, SNO M-TROPICS). The role of trees (i.e., teak trees) and the presence of deep roots on soil nutrient and carbon dynamics was studied using 10-meter deep wells, finely characterized at the scale of soil horizons and root traits. Humidity, pCO_2, pore water composition and root dynamics (through scanner imaging systems) were continuously monitored. In parallel, controlled soil incubation experiments (i.e., microcosms) were performed. Carbon stocks and forms were obtained from dry combustion and Rock-Eval® thermal pyrolysis analyses, while microbial activity and diversity were determined by environmental DNA analysis and incubation experiments.
In agroforestry system, the microbial communities associated with the rhizosphere are more diverse than those of the average soil, with specific taxa such as mycorrhizal fungi. Deep carbon stocks and forms are different in the agroforestry and the irrigated agriculture pits, due to different initial organic matter sources, and deep microbial activity dependent on organic matter input. In agroforestry, the carbon stocks are larger, and carbon forms at depth (9m) are stored in a more stable reservoir. The presence of deep-rooted trees brings root organic matter to the deep soil layers, some of which recalcitrant, and the microbial communities associated with the roots could slow down the organic matter decomposition. Thus, the forms and stocks of carbon in deep agricultural soils, linked to the microbial communities in the environment,

can be modulated by the presence of trees. More detailed functional ecology studies could confirm the hypothesis that carbon reservoirs in agroforestry and irrigated plots have different dynamics due to different rates of decomposition by micro-organisms. This would have implications for the resistance and resilience of such agro-ecosystems in the context of climate change.

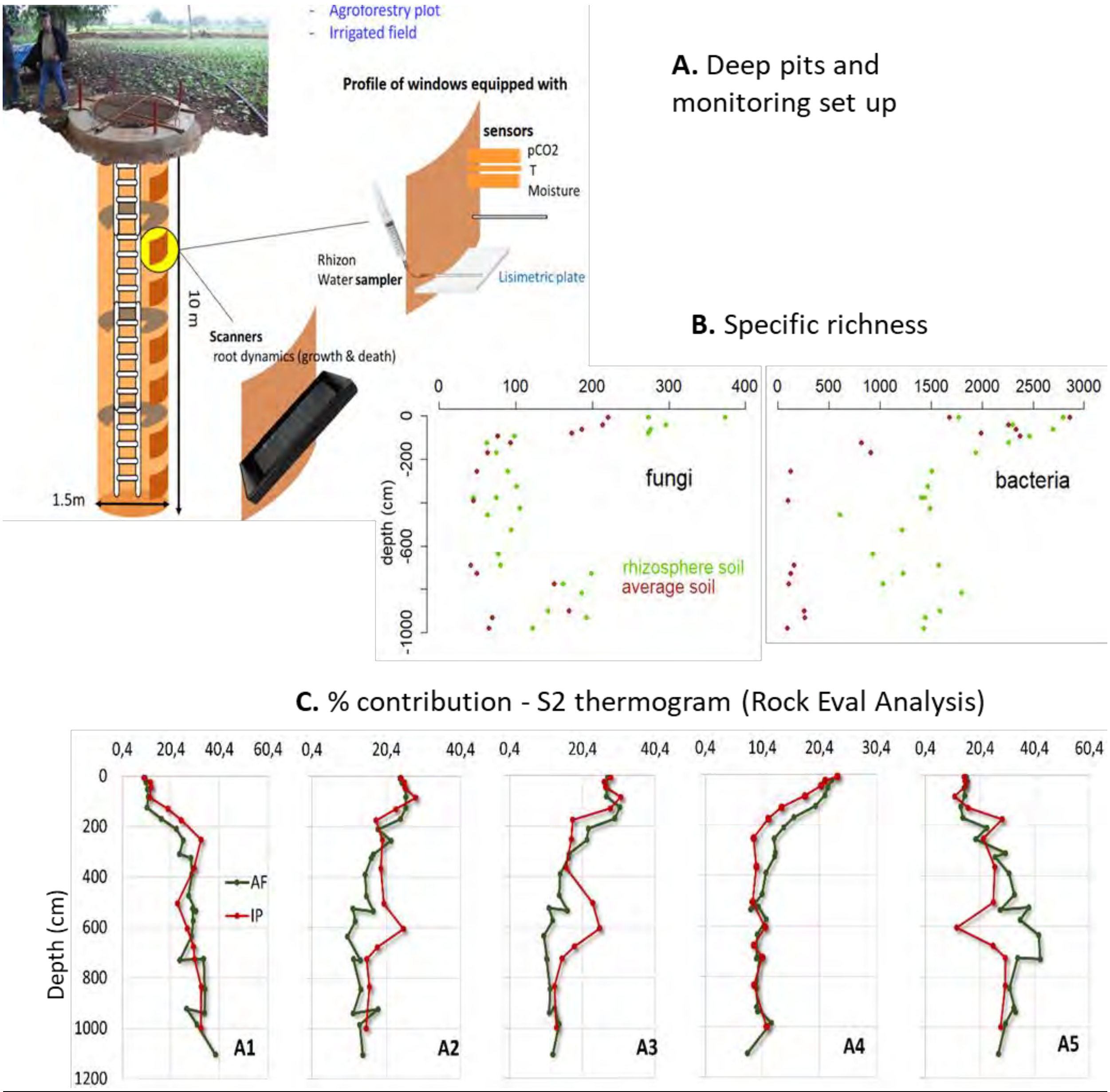

Figure showing A/ the field system with a schematic diagram of the deep pits monitored for root activity, gas chemistry and soil solutions, B/ bacterial and fungi specific richness results comparing populations between the average soil (red) and the rhizosphere soil (green) for the agroforestry pit and C/ the profiles of the different contributions (in %) making up the deconvolution of the S2 thermogram from the Rock-Eval® thermal analyses of AF and IP soils.

Session 4

ABSTRACTS of POSTERS

Soil Carbon in the Ecological Transition
International symposium
24 - 26 January 2024

Species richness of tree plantations affects pathways of carbon incorporation into soil organic matter

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Inventories on forest and plantation soil carbon storage capabilities have often been found to be positively influenced by plant species richness. However, no satisfactory explanation has been reached so far, as, neither primary production or litter recalcitrance have been found in most cases to be sufficiently strong drivers of the observed phenomenon.

We tested the hypothesis that this enhanced C sequestration may derive from modifications in the relative proportions of pathways of C incorporation into SOM, leading to changes in the relative proportions of labile (non-humic, non-phenolic C) and refractory SOM components (humic, phenolic C) and in their physical stabilization by sorption (bound or not bound C) to soil minerals.

We sampled surface soil at two different depths (0-3 and 3-15 cm) in six mixed deciduous plantations located in the upper plain of the Friuli Venezia Giulia region, in the north-east of Italy. Soils have developed under the same climatic conditions and from calcareous parent materials, and are classified as calcaric aric-regosols and chromic endoskeletric cambisols. Plantations had the same tree density and standing age (19 years since reversion from arable land), but differed in the number of tree species (from 1 to 9).

Humic and non-humic substances fractions of soil organic matter (SOM) were obtained by extracting soil (1:10 w/v) first with 0.5M NaOH (non-humic and humic free C) and then by alkaline 0.1M sodium pyrophosphate (non-humic and humic C bound to mineral surfaces by Ca^{2+} bridges, bound C). Extracts were then fractionated by solid phase chromatography on crosslinked polyvynilpyrrolidone to separate non-phenolic substances from humic materials. We also measured soil microbial biomass C by fumigation-extraction (FE) and determined microbial biomass specific respiration rates under optimal mineralization conditions (25°C and 50% WHC) during a 10 days' laboratory incubation.

Species richness affected the relative proportion among SOM fractions and the amount of humic C increased with species richness. In the uppermost mineral soil layer (0-3 cm), free to mineral-bound humic substances displayed a trend contrasting that of the 3-15 cm layer, coherently with the divergent carbon dioxide emissions trends measured during laboratory incubation from samples taken from the two soil layers.

In tree plantations, species richness supports the development of complex interactions among the number of tree species, carbon dioxide emissions and the amount of C stored in free and mineral-bound humic and non-humic fractions. These interactions foster the incorporation of C inputs into more refractory fractions of SOM, either by favouring chemical stabilization through binding with phenols (formation of humic C) or by physical stabilization through binding with mineral components via the establishment of cationic bridges.

Soil Carbon in the Ecological Transition
International symposium
24 - 26 January 2024

Understanding the gas exchange mechanisms between permafrost soils and the atmosphere in Daring Lake (Canada): Implications to the climate change.

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The carbon pool in permafrost soils is estimated at about 1600 Gt, almost twice the concentration of carbon in the atmosphere (Turetsky et al., 2020; Miner et al., 2022). In northern high latitudes, climate warming is responsible for several environmental changes leading to the decomposition of soil organic matter (SOM) and emissions of greenhouse gases (GHG) from the soil into the atmosphere (Szymański et al., 2022). The main aim of this study is to investigate the thermal properties of the SOM in permafrost-affected soils and evaluate the relationship between SOM stability and in-situ gas emissions. In this study, three different ecosystem zones were defined near the Tundra Ecosystem Research Station (TERS) at Daring Lake (Canada) according to the predominate vegetation, soil moisture conditions, and relief as follows: 1) mixed tundra (dwarf shrub/sedge tundra), 2) wetlands, and 3) shrub tundra (Humphreys et al., 2011; Atlas of Canada). An integrated analytical approach was tested here combining in-situ measurements as well as laboratory analysis. During the field campaign, CO_2 and CH_4 fluxes were continuously measured using a Flair box™ device in the mixed tundra and wetland zones. At the laboratory scale, soil samples collected from the active layer (~60 cm thickness) were analyzed using the thermal Rock-Eval® method, whereas carbon isotopic analysis of methane gases sampled from soils were examined using a Picarro® device.

Results indicate that both wetland and mixed tundra zones are mainly dominated by thermolabile organic carbon forms. This is also consistent with high measured atmospheric CO_2 and CH_4 concentrations, suggesting that these zones can be considered the main GHG source in the studied area. Results also suggest that the SOM in shrub tundra zones is probably more resistant to the thermal degradation due to a predominance of thermostable organic carbon forms. In general, the results also suggest that the stabilization of the SOM in these permafrost soils takes place by geochemical interactions between the mineral and organic horizons, and probably under these conditions the SOM is less susceptible to decomposition and to release additional GHG in a warming climate. This geochemical data will be used to develop a soil respiration model that considers thawing of permafrost soils and SOM mineralization.

Organic matter in the archaeological agricultural soils of Gabon

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Abstract :
Raised fields are agrarian systems typical of humid areas in the intertropics. The principle is to raise "the land above the natural surface of the soil, in order to improve agricultural conditions" (Denevan and Turner, 1974). Massively used in the past, today this practice has fallen into disuse, creating vast archaeological sites. These archaeological raised fields have been studied mainly in South America since the 1960s (Denevan, 2002). In Central Africa, the presence of these remains was also observed at the same period (Sautter,1966; Denevan, 2002), but no study of these sites has been carried out until today. Furthermore, the majority of studies on these objects question the topographical extent they represent (Moore 1988, Blatrix et al., 2012; Lee and Walker, 2022), the way they were constructed and managed (Iriarté et al., 2012, Rodrigues et al, 2015), their interest in adapting to local environments (Erikson, 1992; Rodrigues et al., 2018, Lhomme and Vacher, 2002, Lombardo et al., 2011), and the quantity and quality of agricultural production they have enabled (Bruno, 2014, Whitney et al., 2014, Young et al., 2023). However, very few studies investigated the soil organic matter and carbon storage capacity of these systems, and these studies have only been carried out on presently used (i.e. still cultivated) raised fields (Rodrigues et al., 2020). In order to fill these gaps, this work focuses on the raised fields of Gabon, at the Matadi site, which is located in a flood zone of the Agouma, a tributary of the Ogouée. The archaeological site is represented by a totally transformed area ~2.5 km^2, made up of elongated fields approximately ~30 m long by ~8 m wide and around 0.8 m high. The aim of our work was to understand the nature of these structures in terms of organic matter and to determine whether they can store carbon. 9 fields and 4 interfields were auger sampled, as well as 4 field profiles sampled with apparent densities. The physico-chemical analyses, and in particular the Rock-Eval analysis, showed a strong similarity between the 9 fields. They all show a gradient over depth in texture, carbon content and the type of organic matter they contain. Furthermore, by comparing the OM of the fields and interfields, it was shown that the interfields are made up of two layers, with a layer of fresh organic matter on the surface and a layer of mature organic matter at depth. The fields have three layers, the first two common to the interfields, but also an intermediate layer, with organic matter that is weak in C-O and C-H bonds, and more thermoresistant. We hypothesise that the OM making up these structures is rich in charcoal. This result raises questions about past agriculture, which potentially includes management practices involving fire. By integrating these results with the cartography of the site, we were able to give an initial estimate of the carbon stocks that such systems may represent. The ultimate aim is to show that these archaeological sites need more attention, as they represent important and sustainable carbon sinks that need to be understood, studied and protected.

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Soil organic carbon stock change following perennialization: A meta-analysis

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Abstract: Perennial cropping (PC) systems are attracting global attention as sustainable biomass producers and as a climate change mitigation strategy due to their potential to sequester soil carbon (C). However, questions remain on how long PCs can sequester C in soils and how global climate, soil, and plant properties affect soil organic carbon (SOC) stocks. We conducted a meta-analysis synthesizing 51 publications (351 observations at 77 sites) distributed over different pedo-climatic conditions to scrutinize the effect of perennialization on SOC accumulation compared with two benchmark annual systems (monoculture and crop rotation). To better understand the factors influencing SOC accumulation, we used moderator analysis including potential factors like climate zone, soil textural class, soil pH class, perennial crop age, perennial vegetation type, and functional photosynthetic types. Results showed that PCs significantly increased SOC stock by 16.6% and 23.1% at 0-30 cm depth relative to reference annual monoculture and crop rotation systems, respectively. Shortly after establishment (<5 years), PCs reduced SOC stock, while long duration (>10 years) of perennialization significantly increased SOC stock by 30% and 36.4% compared with annual monoculture and crop rotation system. Compared with both reference annual systems, PCs significantly increased SOC stock regardless of their functional types (C3, C4, or C3-C4) and vegetation type (woody or herbaceous). Soil pH had a significant impact on SOC, with more C accumulation in alkaline soils. In contrast, the effect of soil textures showed no significant impact, possibly due to a lack of observations from each textural class and mixed pedoclimatic effects. Time effect of perennialization revealed a sigmoidal increase of SOC stock until about 20 years thereafter reaching a steady-state level.

Annex:

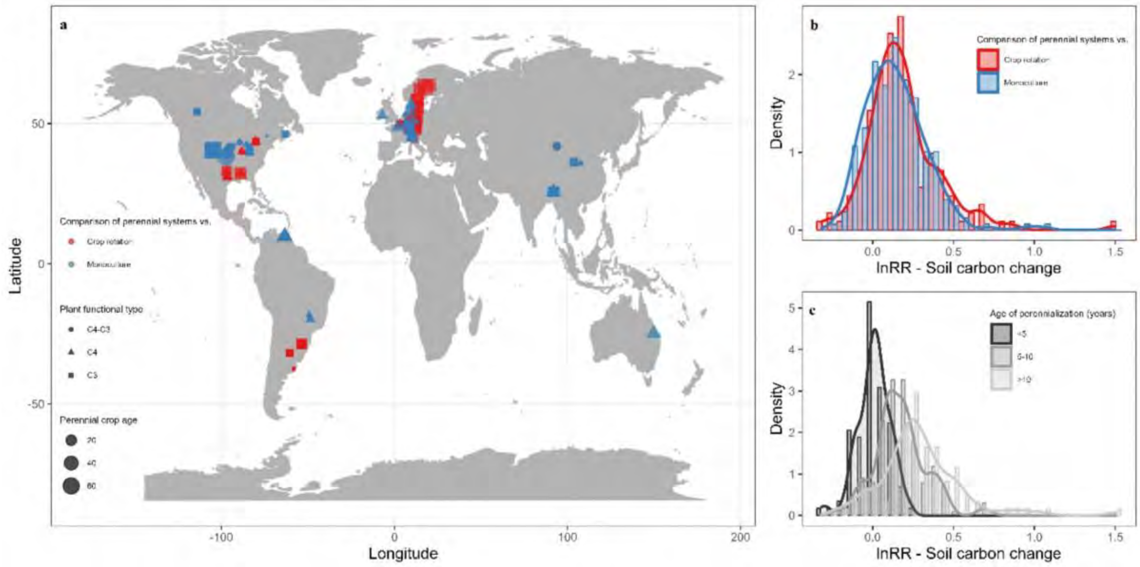

Figure 1: Geographical distribution of the 51 studies across 77 experimental sites included in the analysis (a). Colours indicate the reference annual systems to compare with perennial crops, shapes indicate the functional types of perennial crops (PFT; C3, C4, or C3-C4), and sizes indicate the age of perennial crops, distribution of the log-transformed response ratio (lnRR) of soil carbon change under reference annual systems (b) and distribution of perennialization age (years) (c)

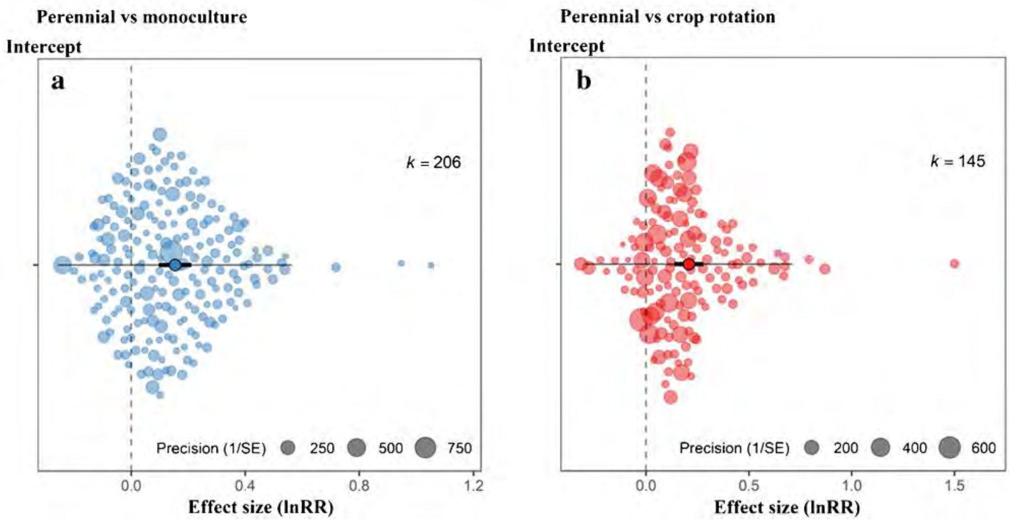

Figure 2: Effect of perennialization on soil organic carbon stock change compared against (a) monoculture and (b) crop rotation. Meta-analytic model showing mean estimates with dark coloured circles, 95% confidence interval with thick whisker, 95% prediction interval with thin whisker, and individual effect sizes scaled by their precision (i.e. inverse of the standard error) with light coloured circles. k indicates the number of effect sizes. The dashed vertical line shows null log response ratio

Characterization of organic matter in peat samples with Pyrolysis gas chromatography coupled to mass spectrometry (Py-GC/MS): from methodological challenges to identification of relevant molecular indicators.

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It is commonly agreed today that there is a need for advanced characterization techniques for organic matter. The aim of this study is to develop an analytical methodology based on a thermal analysis, the Pyrolysis gas chromatography coupled to mass spectrometry (or Py-GC/MS), while avoiding sample preparation steps. Sample preparation approaches like extraction or fractionation can result in bias in compositions and thus in conclusions. Thermal analysis combines the advantages of being a direct analysis for solid samples, and of thermal stability, which is directly correlated to biogeochemical stability (Albrecht et al., 2015; Cécillon et al., 2018; Sanderman and Grandy, 2020).

An analytical workflow based on Py-GC/MS was optimized, involving six pyrolysis temperature steps ranging from 240°C to 1200°C. The separation of compounds over the GC column was optimized, as well as the detection with mass spectrometry, providing a thorough workflow for molecular identification.

It was then applied over ten peat samples from Ngaoundaba peat from Cameroon to characterize the organic matter preserved in this sedimentary sequence (0 to 10.000 years). Several molecules from different families (lignin, polysaccharides, aromatics, phenols, proteins) could be identified at pyrolysis temperatures comprised between 350 and 550°C.

Doublet peaks with alkenes/alkanes of increasing carbon chain lengths were identified at pyrolysis temperatures of 450°C (Figure 1). This observation was also made by Albignac et al. (2023), who used this result to distinguish between natural and synthetic organic matter like polymers. Molecular indicators were searched as markers of sample features, like age/depth or climatic conditions for example. These promising results pave the way for future research in this field, as the coupling of thermal analysis with a powerful molecular analysis like GC/MS gives valuable insight into complex solid sample composition.

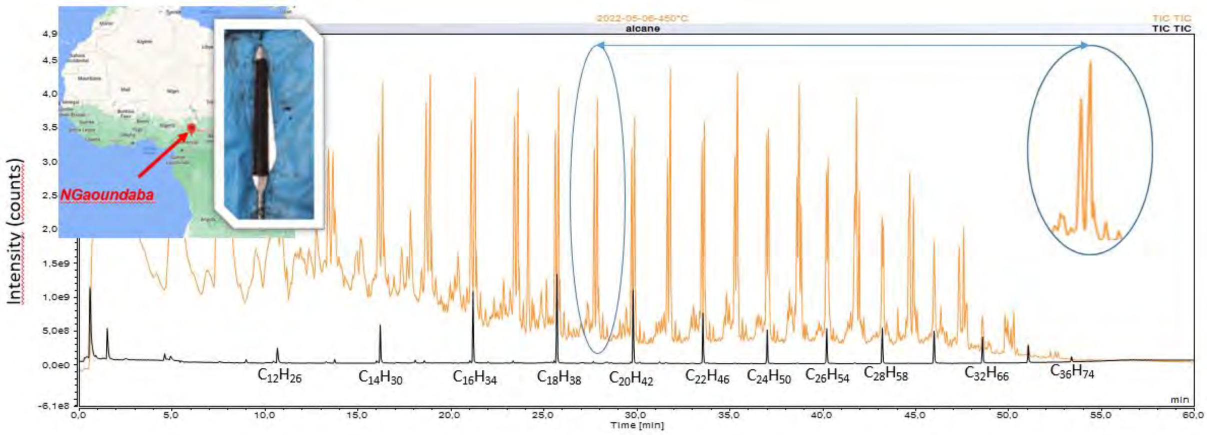

Fig. 1 - GC/MS results after a pyrolysis at 450°C for a 7500 year-old peat sample

Soil Carbon in the Ecological Transition
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Variability and drivers of sediments organic carbon stock in the Arcachon Bay (France)

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Arcachon Bay (40 km² to 150 km² according to the tide) is an iconic ecosystem of the French Atlantic coast. It has been experiencing a major decline in seagrass (*Zostera noltei*) meadows coverage for several decades (Auby *et al.* 2011), leading to a net decline in its carbon sequestration potential (Ribaudo *et al.* 2016). Characterising and deciphering the variability of these carbon stocks is thus required in the context of meadows ecological restoration (Greiner *et al.* 2013).
In the context of the EU RestCoast project and the PROSPERE project, 15 sampling sites have been selected within Arcachon Bay (Fig. 1). For each site, two paired plots - with and without seagrass meadows- have been sampled. Each sediment sample (0-10 cm and 0-30 cm depths) has been characterised in terms of total and organic carbon contents, nitrogen content, bulk density and granulometry (with 5 spatial sub-replicates for C and N). As current speeds are expected to be key drivers of carbon storage of *Zostera* meadows (Dahl et al. 2016, 2018), the Delft-Flexible Mesh modelling suite, coupling waves formation and propagation with hydrodynamics, has been implemented. Hydrodynamics simulations have been used to estimate the distribution of water levels, current speeds, and emersion time at various time scales (tidal range, monthly, seasonal and annual) based on a 3 years (2016-2019) simulation. Data analyses show an increase of organic carbon content with finer granulometry probably driven by sedimentation speed of exogenous sestonic organic matter (i.e. originating from the watersheds that feed the Arcachon Bay) as suggested by Greiner *et al.* (2016). Most paired plots present similar granulometry, which can be caused by bare substrate plots being positioned within the hydrodynamic influence area of the nearby seagrass meadows. This highlights the relevance of considering other drivers to disentangle the spatial variability of sediment organic matter drivers (Greiner *et al.* 2016). Several tests have been done to explain site variability with hydrodynamics simulations outputs.
The relationships between granulometry, carbon content and hydrodynamics drivers are discussed in the context of results upscaling at the Arcachon Bay scale and forecasting ecological restoration actions impacts on carbon storage.

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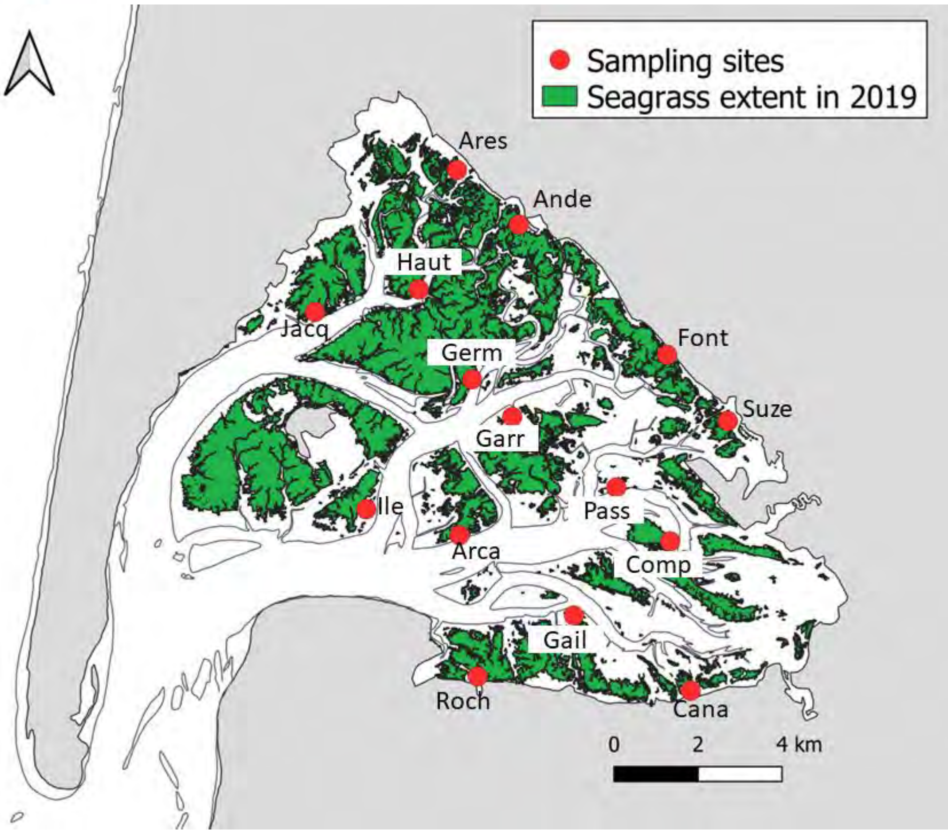

Fig. 1. Map of the Arcachon bay (France) with the location of the 15 selected sites.