Design of a high-resolution and dynamic soil organic carbon monitoring system for agricultural land

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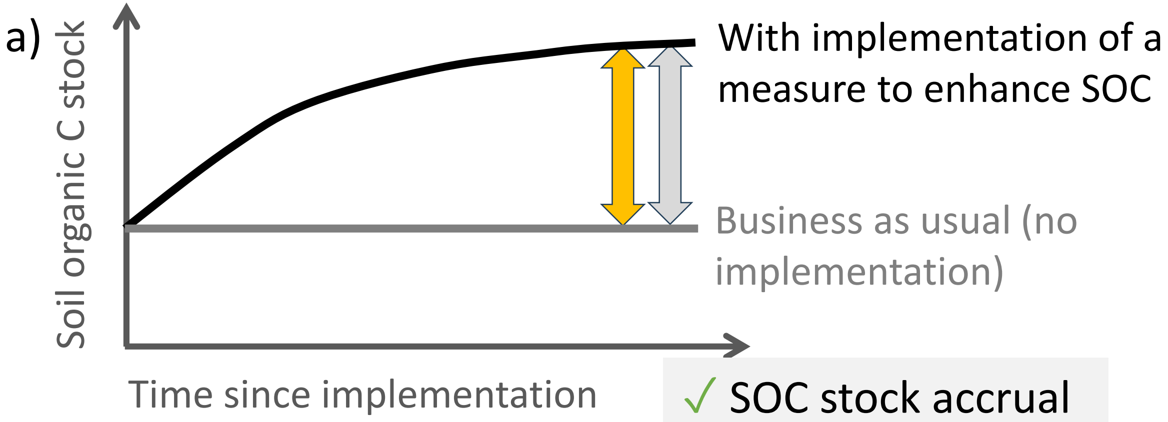
1- INRAE, France
2- ILVO, Belgium
3- Thunen Institute, Germany
4- Wageningen Research, The Netherlands
5- Aarhus University, Denmark
6- CREA, Italy

EJP SOIL
European Joint Programme

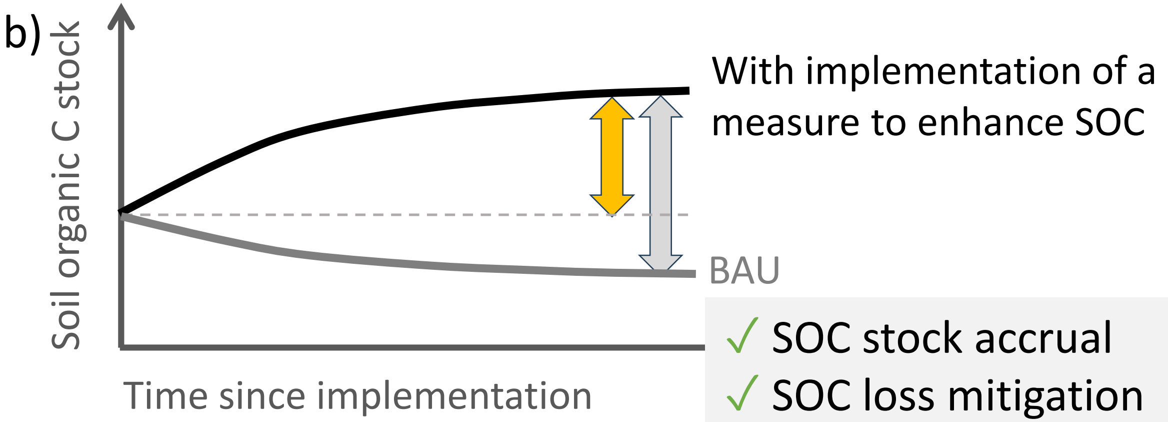
INRAE

Expected outcome?

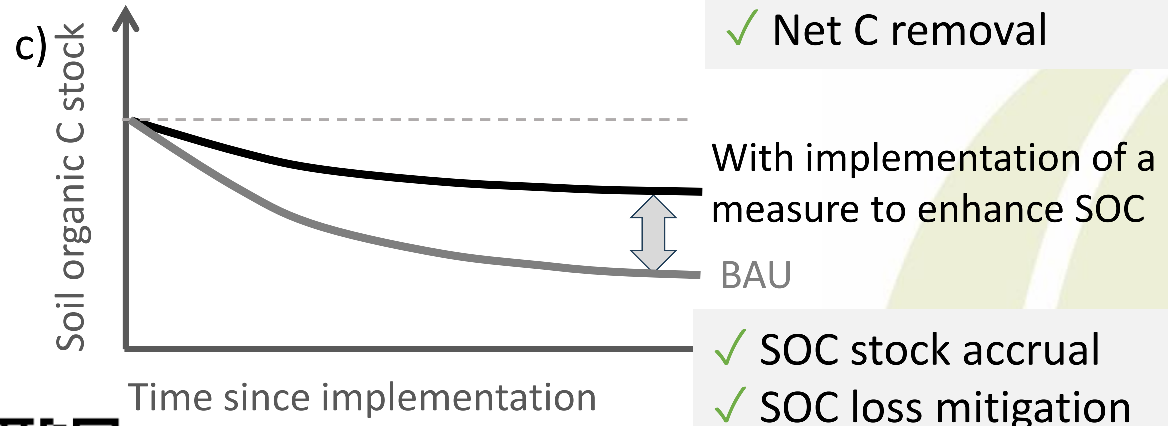
More Soil Organic Carbon for GHG mitigation & for soil health



✓ SOC stock accrual
✓ C sequestration
✓ Net C removal



✓ SOC stock accrual
✓ SOC loss mitigation
✓ C sequestration
✓ Net C removal



✓ SOC stock accrual
✓ SOC loss mitigation
✗ C sequestration
✗ Net C removal

⇕ SOC stock accrual ⇕ C sequestration in soil

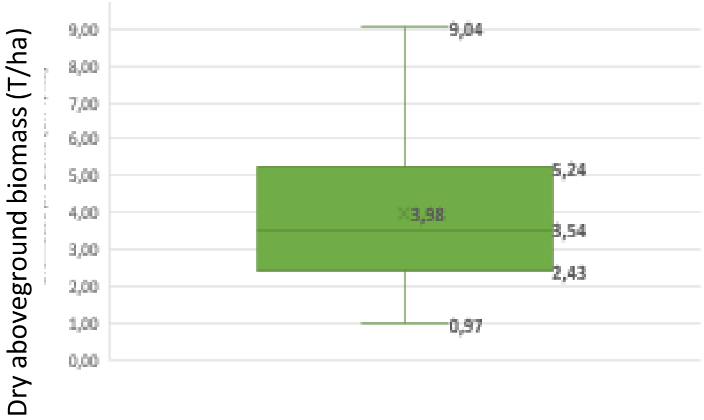
Need to quantify SOC stocks at:
➜ Time 0
➜ Business as usual scenario

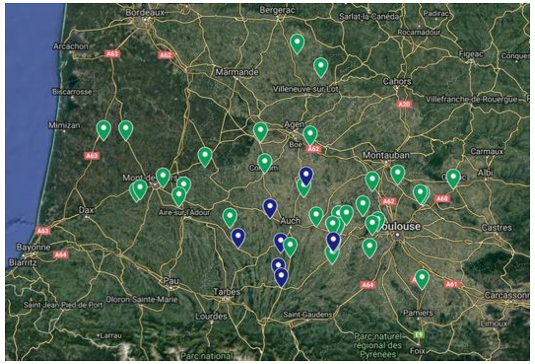
A.Don et al. 2023 GCB

Why a results-based MRV system ?

Because additional SOC storage of a given measure depends on pedoclimatic conditions & management

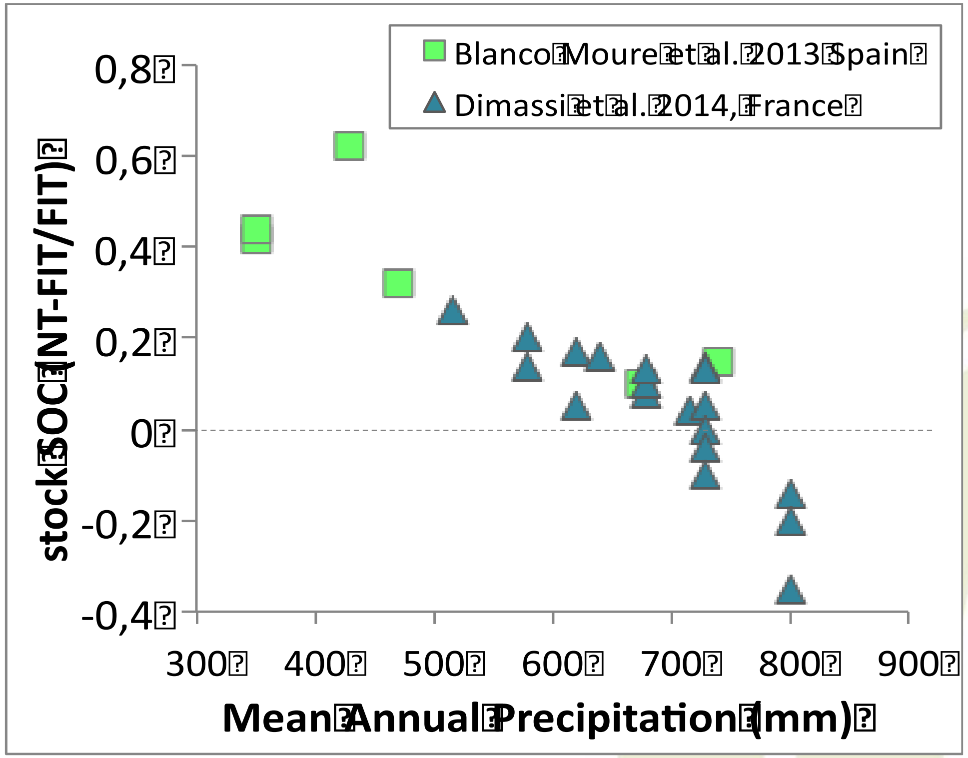
Cover crops:





Inter-crop spatial variability : In-situ cover crop biomass measurements at 57 plots in South West France (©E. Cescia, INRAE)

No-tillage:

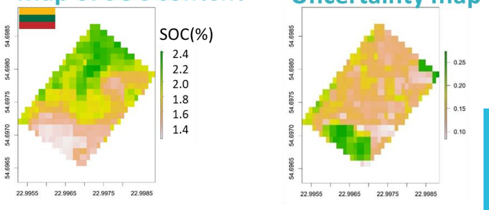


Measuring, modelling ? Why a “hybrid” MRV system ?

Direct soil sampling and SOC measurement ?

- Sensitivity :
  - Small Δ over large stocks
  - Slow changes
  - Spatial variability

=> High costs!

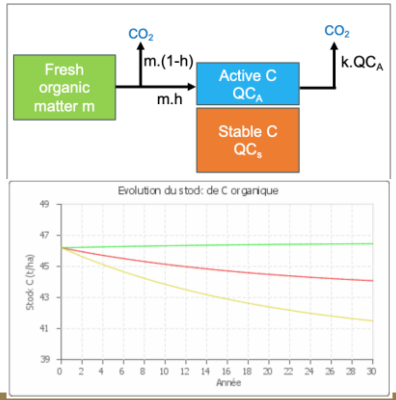


Castaldi et al., 2023

Direct SOC measurement via remote sensing?

- Accuracy and uncertainty
- C contents not stocks

=> Not mature yet for SOC !



Modelling?

- Detailed input parameters needed
  - Soil texture, type
  - Initial SOC
  - Management (e.g, rotation, tillage, fertilisation, etc)

⇒ High administrative burden!

⇒ Explore other info sources..

Example of Soil C Monitoring, Reporting and Verification approach

MARVIC
MRV for carbon farming
Funded by the European Union

A FARM DATA M R

B REMOTE SENSING M R V

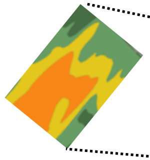
C DATASOURCES M R

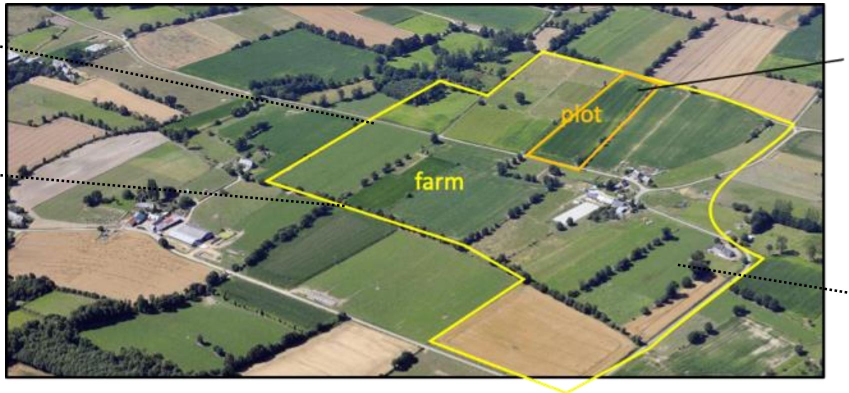
D CROP-SOIL MODELS

E SOIL SAMPLING & MAPPING M V

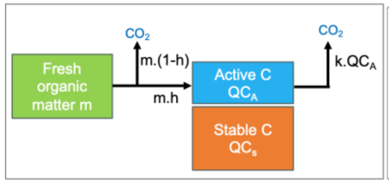
F SAMPLING ALGORITHMS

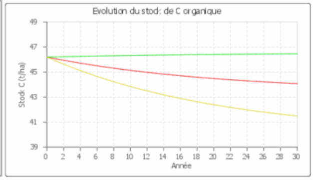
G BENCHMARK SITES M





Evolution of SOC stocks over time





CIRCASA

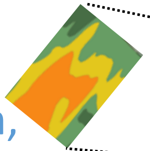
Adapted from Smith et al. 2020, GCB Ruysschaert et al. 2022

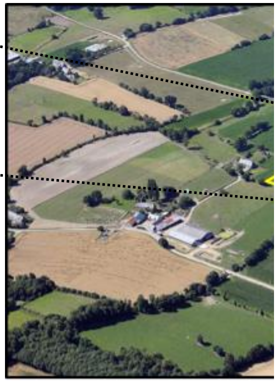
1- Eligibility check

MARVIC
MRV for carbon farming
Funded by the European Union

A **FARM DATA**
- Field/farm/ IACS data
- Management data

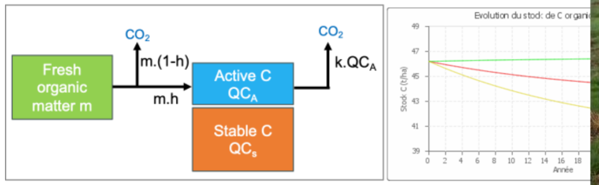
B **REMOTE SENSING**
- Activity data (crop rotation, harvest, tillage operations etc..)
- Biomass
- Soil properties





C **DATASOURCES**

D **CROP-SOIL MODEL**



- Management options envisioned ?
  - Efficiency / SOC accrual?
  - Potential leakage?
  - Environmental & biodiversity potential effects?
  - Additionality?

The issue of organic amendments: no net C removal

Chenu et al. 2019 STILL

2- Quantifying potential SOC accrual & C removal

MARVIC MRV for carbon farming
Funded by the European Union

A FARM DATA (M)
- Field/farm/ IACS data
- Management data

G BENCHMARK SITES (M)

B REMOTE SENSING (M)
- Activity data (crop rotation, harvest, tillage operations etc..)
- Biomass
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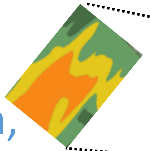
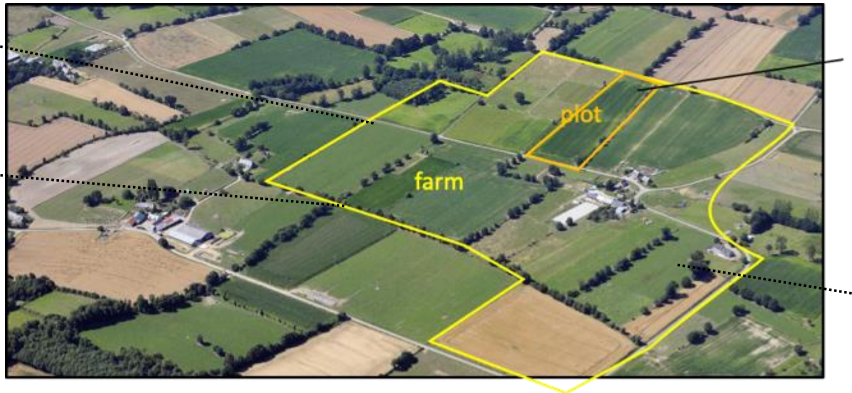


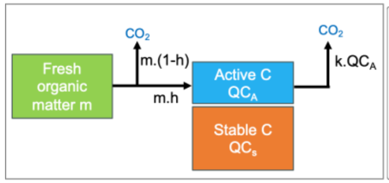


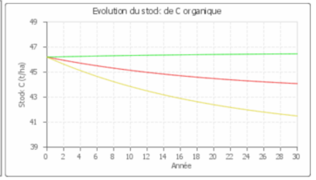
F SAMPLING ALGORITHMS

E SOIL SAMPLING & MAPPING (M)
- Initial sampling
-

C DATASOURCES (M)
- climate
- soil
- land cover

D CROP-SOIL MODELS → **Evolution of SOC stocks over time**
- Soil models estimating SOC/GHG
- Vegetation models estimating C budget





3- Reporting and verifying

MARVIC MRV for carbon farming

Funded by the European Union

A FARM DATA (M) (R)
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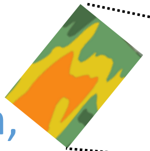

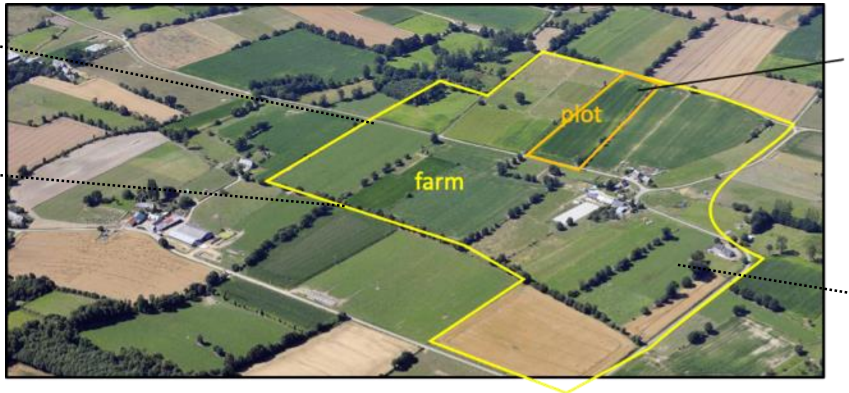

C DATASOURCES (M) (R)
- climate
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G BENCHMARK SITES (M)

F SAMPLING ALGORITHMS

Where, how many, when and how to sample

E SOIL SAMPLING & MAPPING (M) (V)
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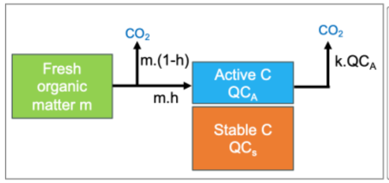
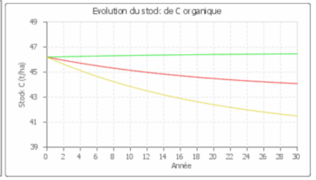
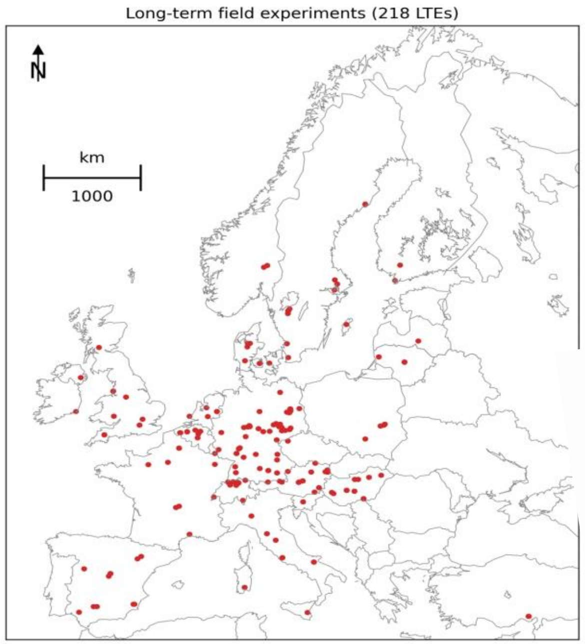


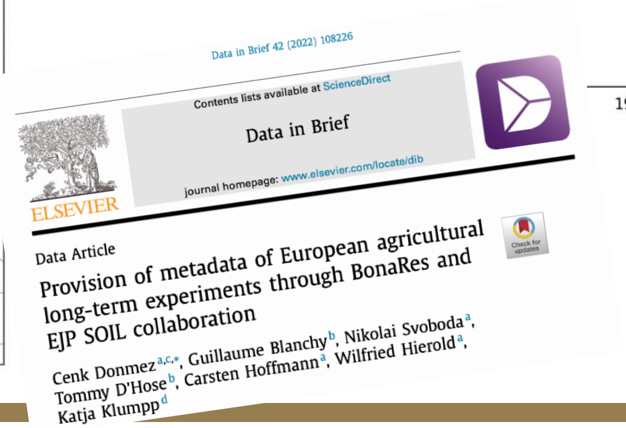


Benchmark sites

G BENCHMARK SITES M

- Testing C farming practices, EF
- Measuring GHG fluxes
- Developing, calibrating & validating models





Data in Brief 42 (2022) 108226

Contents lists available at ScienceDirect

Data in Brief

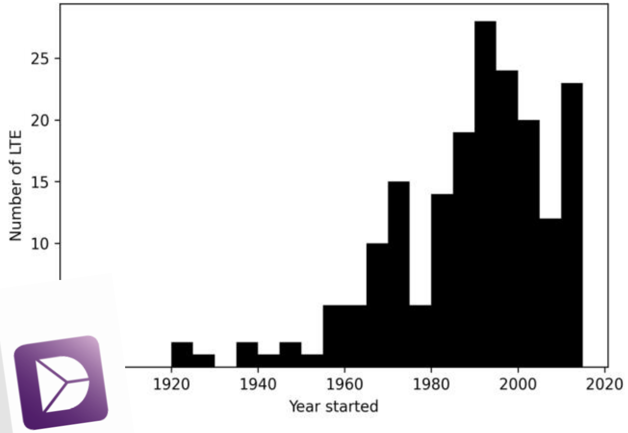
journal homepage: www.elsevier.com/locate/dib

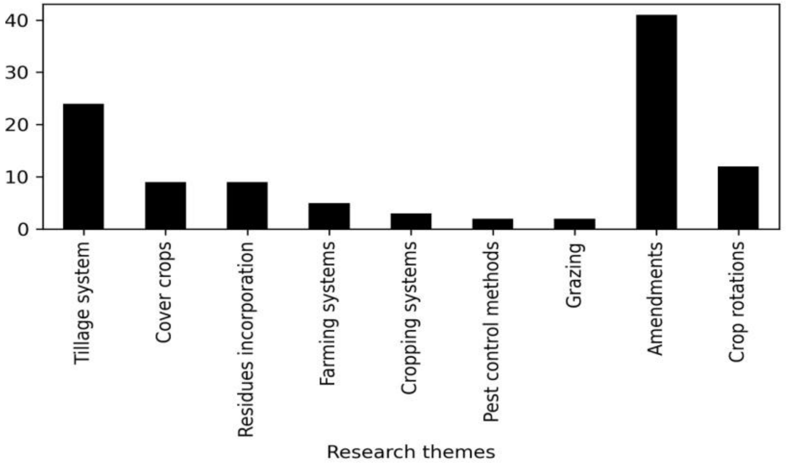
ELSEVIER

Data Article

Provision of metadata of European agricultural long-term experiments through BonaRes and EJP SOIL collaboration

Cenk Donmez[a,c,*], Guillaume Blanchy[b], Nikolai Svoboda[a], Tommy D'Hose[b], Carsten Hoffmann[a], Wilfried Hierold[a], Katja Klumpp[d]



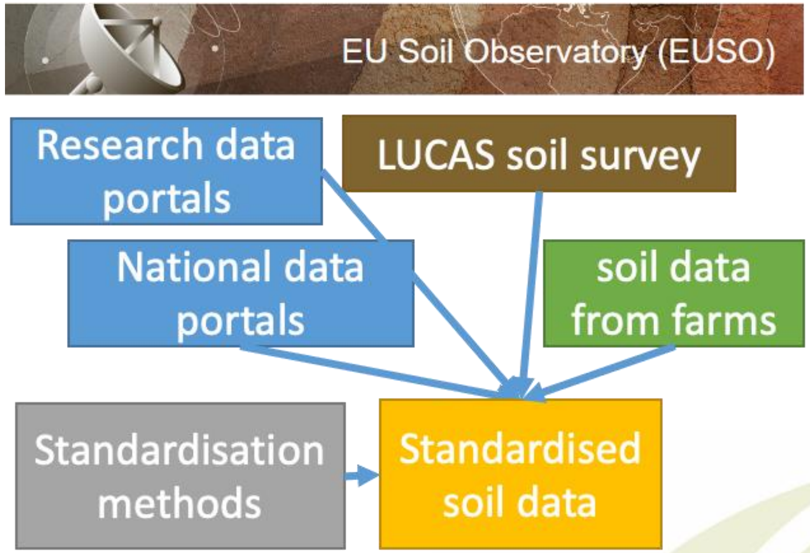


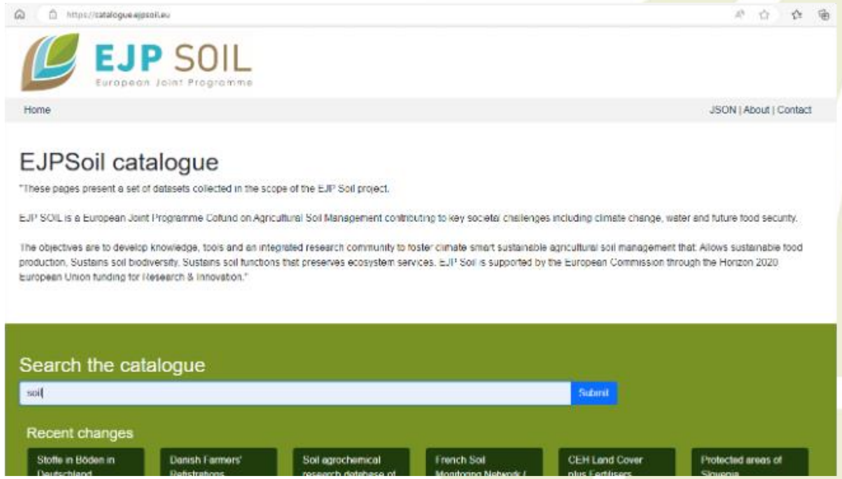
https://lte-eu.bonares.de/experiments

Domnez et al. 2022, Data in Brief

Hybrid, high resolution, dynamic MRV approach

- **Smart assembly** of building blocks (operational processing chains)
- **Automated inputs to models:** as much as possible
  - **Remote sensing**: crop types, carbon inputs, farm activities, soil properties
  - Link with already **publicly available existing data**: e.g. LPIS, GSAA, LUCAS, national databases, research databases
  - Work on **data harmonisation/standardization and interoperability** (e.g. work EJP SOIL WP6, EUSO, Soil Mission, SoilWise etc)
  - Link with **already recorded farm data** (e.g. lab data, harvest machinery, farm management systems) & with **regional data spaces**, e.g. farm data sharing platform https://www.djustconnect.be/en





How can such a system comply to the Regulation on Carbon Removals Certification QU.A.L.ITY criteria?

QUANTIFICATION

Carbon removal activities are measured against a baseline and are net of supply-chain emissions

✓

- Time 0 measurements/ soil data
- Modelling of BAU
- GHG emission estimates (emission factor, modelling)

ADDITIONALITY

Carbon removal activities go beyond standard market practices and what is legally required to the operator

✓

- Eligibility step
- Farm data
- Remote sensing/farm practices

LONG-TERM STORAGE

Certificates clearly account for the duration of carbon storage and distinguish permanent storage from temporary storage

✓

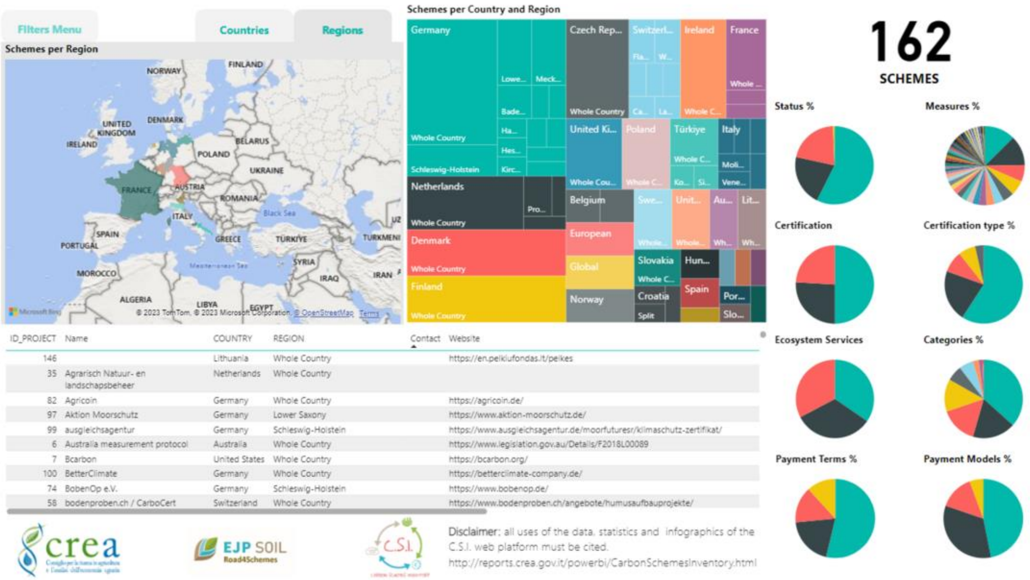
- Remote sensing for C input and activity
- Modelling the effects of climate change on biomass and SOC

SUSTAINABILITY

Carbon removal activities do not harm the environment or even benefit other environmental objectives such as biodiversity

- Evaluating ecosystem services provision and biodiversity

How can such a system comply to the Regulation on Carbon Removals Certification QU.A.L.ITY criteria?



EJP SOIL SIREN
Inventory of current indicator systems

EJP SOIL SERENA
Common definitions, thresholds inventory/proposal

EJP SOIL MINOTAUR
Prioritizing biodiversity indicators

EJP SOIL WP6
WP6: "D6.5 Guidelines for accounting and mapping agricultural soil carbon, fertility and degradation changes at different scales"

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Soil Health BENCHMARKS

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✓

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SUSTAINABIL**ITY**

Carbon removal activities do not harm the environment or even benefit other environmental objectives such as biodiversity

✓ ✗

- Evaluating ecosystem services provision and biodiversity

Design of a high-resolution and dynamic soil organic carbon monitoring system for agricultural land

- Store more C in soils **for ecosystem services and GHG mitigation**. Not only C!
- **“Mixed” carbon farming systems**: practice-based & results-based MRV both needed
- **Adapted to different context of application**
  - National inventories, CAP, agri-food sector insetting, voluntary markets
- **Hybrid MRV systems** : measurements & modelling & realistic biomass estimates through remote sensing
- **Automated**, **modular**, **large scale but high resolution, uncertainty analysis and low cost**
- **Issues:**
  - The **references**: time 0, BAU, regional standard baseline
  - **Soil data**: spatial resolution, harmonization
  - **Data assimilation & assemblage**

Several projects working on it now !

MARVIC – MRV for carbon farming

EU Soil Observatory (EUSO)

SoilWise – Knowledge & data flows

MRV4SOC

EU MISSIONS – Soil deal for Europe

EJP SOIL – European Joint Programme

ORCaSa – Because soil carbon matters

Thank you for your attention

EJP SOIL
European Joint Programme
EJP SOIL has received funding from the European Union's Horizon 2020 research and innovation programme: Grant agreement No 862695

www.ejpsoil.eu
claire.chenu@inrae.fr

References

- Castaldi, F., Koparan, M.H., Wetterlind, J., Zydelis, R., Vinci, I., Savas, A., Kivrak, C., Tunçay, T., Volungevicius, J., Obber, S., Ragazzi, F., Malo, D., Vaudour, E., 2023. Assessing the capability of Sentinel-2 time-series to estimate soil organic carbon and clay content at local scale in croplands. Isprs Journal of Photogrammetry and Remote Sensing 199, 40-60.DOII
- Chenu, C., Angers, D.A., Barré, P., Derrien, D., Arrouays, D., Balesdent, J., 2019. Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations. Soil and Tillage Research 188, 41-52.
- Dimassi, B., Mary, B., Wylleman, R., Labreuche, J., Couture, D., Piraux, F., Cohan, J.-P., 2014. Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years. Agriculture, Ecosystems & Environment 188, 134-146.
- Don, A., Seidel, F., Leifeld, J., Katterer, T., Martin, M., Pellerin, S., Emde, D., Seitz, D., Chenu, C., 2023. Carbon sequestration in soils and climate change mitigation-Definitions and pitfalls. Glob Chang Biol, e16983.DOII
- Donmez, C., Blanchy, G., Svoboda, N., D'Hose, T., Hoffmann, C., Hierold, W., Klumpp, K., 2022. Provision of metadata of European agricultural long-term experiments through BonaRes and EJP SOIL collaboration. Data in Brief 42.DOII
- Pique, G., Fieuzal, R., Al Bitar, A., Veloso, A., Tallec, T., Brut, A., Ferlicoq, M., Zawilski, B., Dejoux, J.F., Gibrin, H., Ceschia, E., 2020. Estimation of daily CO2 fluxes and of the components of the carbon budget for winter wheat by the assimilation of Sentinel 2-like remote sensing data into a crop model. Geoderma 376.
- Ruyschaert G. et al. 2023. MARVIC Grant Agreement. Soil Mission projects
- Smith, P., Soussana, J.F., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., Batjes, N.H., van Egmond, F., McNeill, S., Kuhnert, M., Arias-Navarro, C., Olesen, J.E., Chirinda, N., Fornara, D., Wollenberg, E., Alvaro-Fuentes, J., Sanz-Cobena, A., Klumpp, K., 2020. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biology 26, 219-241.
- Vaudour, E., Gholizadeh, A., Castaldi, F., Saberioon, M., Boruvka, L., Urbina-Salazar, D., Fouad, Y., Arrouays, D., Richer-de-Forges, A.C., Biney, J., Wetterlind, J., Van Wesemael, B., 2022. Satellite Imagery to Map Topsoil Organic Carbon Content over Cultivated Areas: An Overview. Remote Sensing 14.
- Wijmer, T., Al Bitar, A., Arnaud, L., Fieuzal, R., and Ceschia, E.: AgriCarbon-EO: v1.0.1: Large Scale and High Resolution Simulation of Carbon Fluxes by Assimilation of Sentinel-2 and Landsat-8 Reflectances using a Bayesian approach, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-48, 2023.

Additional slides

EJP SOIL
European Joint Programme

EJP SOIL has received funding from the European Union's Horizon 2020 research and innovation programme: Grant agreement No 862695

Example of Soil C Monitoring, Reporting and Verification approach

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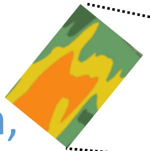

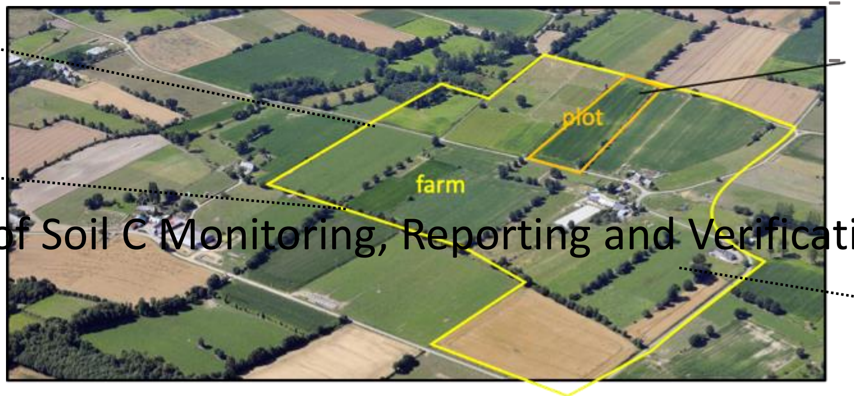

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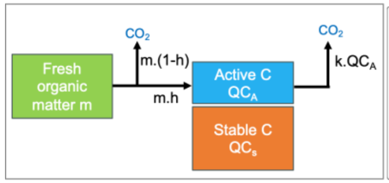
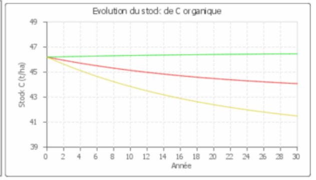




Evolution of SOC stocks over time

G BENCHMARK SITES (M)
- Testing C farming practices, EF
- Measuring GHG fluxes
- Developing, calibrating & validating models

F SAMPLING ALGORITHMS

Where, how many, when and how to sample

E SOIL SAMPLING & MAPPING (M) (V)
- Initial sampling
- Ground-truthing for V

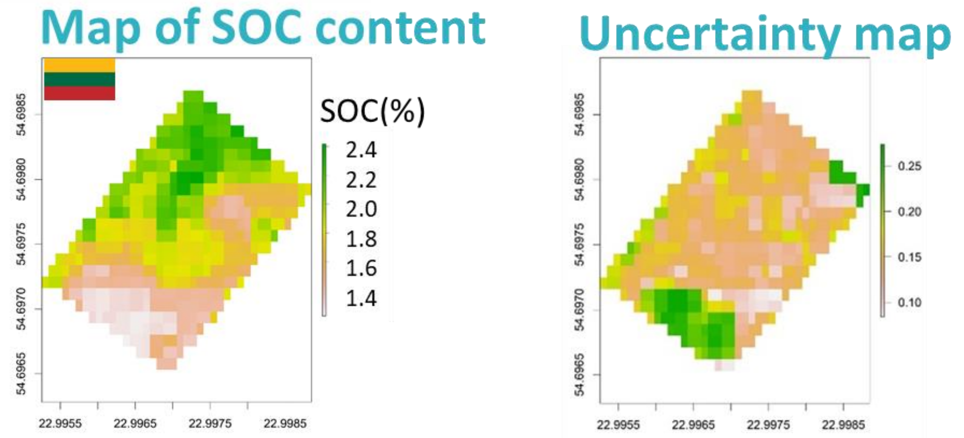
Direct Remote sensing of SOC

For now:

- accuracy / uncertainty of the predicted SOC maps according to several methods and scales is still under investigation
- content considered rather than stock
- spatial uncertainties might be large but most often not provided
- regions with arid/semi-arid climate have intrinsic cumulated scientific locks …under investigation
- need of field samples +agricultural practices

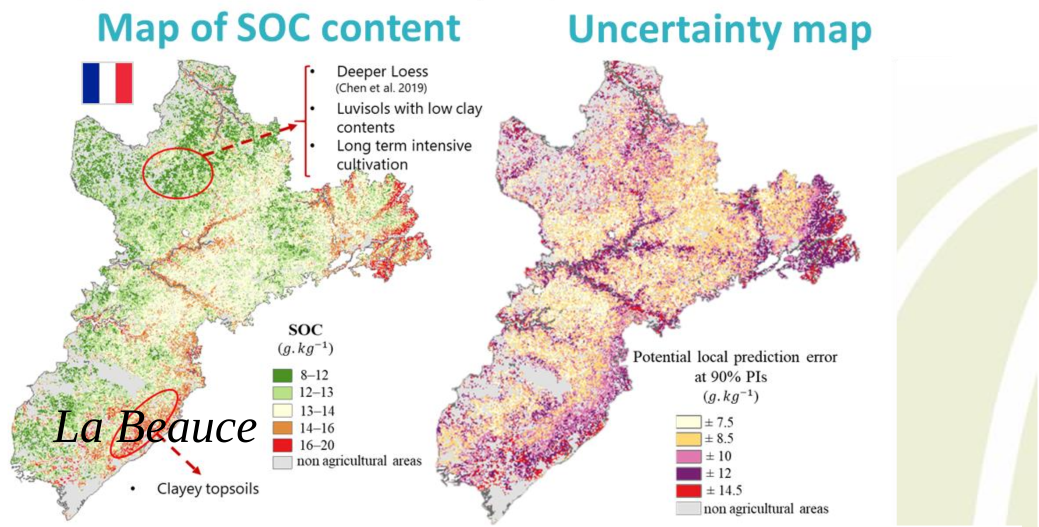
Vaudour et al., 2022 - doi.org/10.3390/rs14122917
Richer-de-Forges et al., 2023 - doi.org/10.3390/rs15123070

local scale
(field 2.8 ha)



Castaldi et al., 2023 - doi.org/10.1016/j.isprsjprs.2023.03.016

regional scale
($4838\ km^2$)

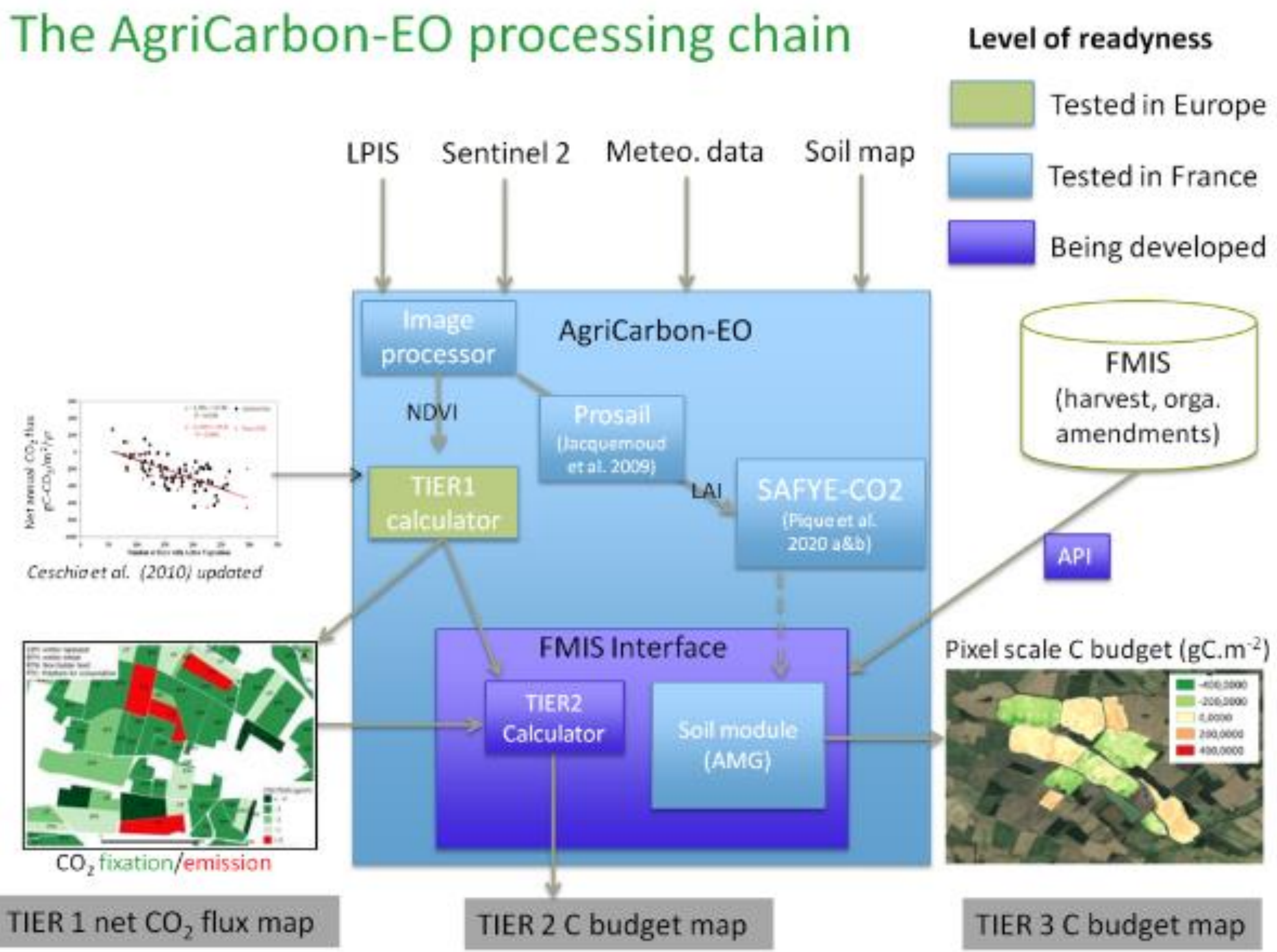


Urbina-Salazar et al., 2023 - doi.org/10.3390/rs15092410

Not mature enough to be used as direct input in C balance modelling approach
➔ keep on using in situ data or derived maps for model initialisation + use as input for smart sampling strategies

EJP SOIL
European Joint Program

Example of MRV operational processing chain



Source: Eric Ceshia, INRAE, FR