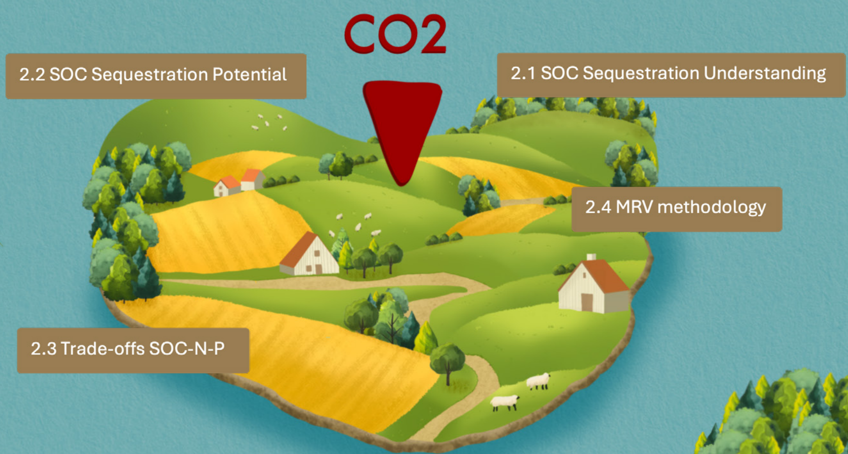
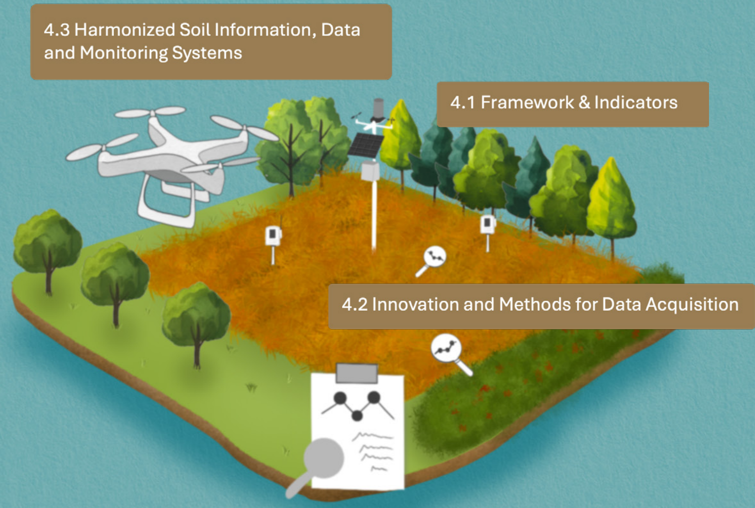
Towards climate-smart sustainable management of agricultural soil

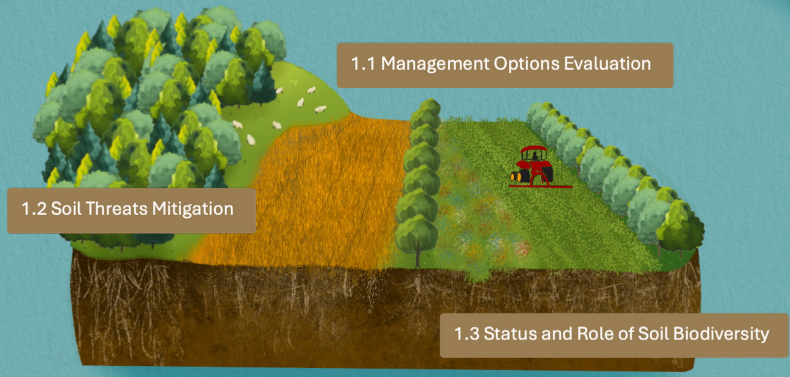
Outputs of the research programme EJP SOIL European co-funded research programme.



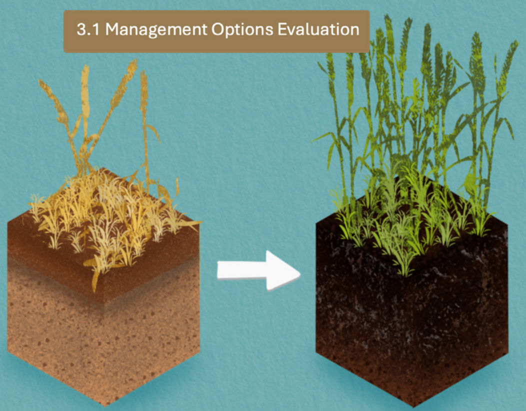
2. Climate Change Mitigation



4. Soil Information Asessing & Monitoring



1. Sustainable Land Management



3. Climate Change Adaptation

5. Fostering Adoption

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1. Sustainable land Management

Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing, either the soil functions that enable those services or biodiversity, as defined by FAO (2015). Sustainable soil management enables agricultural soils multifunctionality.

At the start of EJP SOIL, stakeholder consultations identified that the main soil challenges across countries and regions are i) maintaining and increasing soil organic carbon (SOC); ii) maintaining optimal soil structure; iii) avoiding soil erosion; iv) enhancing nutrient retention and use efficiency; v) avoiding soil sealing; vi) enhancing water storage capacity, and vii) enhancing soil biodiversity (Thorsøe et al., 2023). Soil salinization was expressed as a particular challenge in Southern Europe and Turkey.

EJP SOIL has focused primarily on soil organic carbon stocks, soil erosion, soil structure and habitat for soil biota within the internal projects i-SoMPE, SoilCompaC, SCALE, EOM4SOIL and MINOTAUR, and the external projects SoilSymbiotics, WISH-ROOTS, ClimateCropping, SANCHOSTHIRST, AGROCOMPOSIT, SOIL-HEAL and CropGas.

1.1 Management options evaluation

The soil-improving management strategies receiving most attention in research and practice in EJP SOIL countries are i) reduced and no tillage, ii) crop rotations and cover crops, iii) the use of organic fertilizers and amendments, iv) methods for efficient fertilization, and v) drainage systems and irrigation scheduling (Paz et al, 2024; Thorsøe at al., 2023). Despite this, Heller et al. (2024) showed a low adoption of soil improving management practices (including those mentioned above) in Europe.

Management options evaluations in the EJP SOIL mobilized European mid- and long-term experiments that had been inventoried and of which characteristics are available in a meta-dataset (https://lte-eu.bonares.de/experiments, Donmez et al. 2022, Blanchy et al. 2023).

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1.2 Soil threats mitigation

EJP SOIL projects mainly focused on soil compaction and on water erosion in relation to connectivity in landscapes. Subsoil compaction is very persistent and that recovery strategies exist, but have low recovery rates (e.g. Bakema et al., 2023). The transport of sediment by water erosion depends strongly on the connectivity of water and sediment at landscape scale. Strategies were identified to integrate landscape connectivity into erosion models and improved soil erosion risk knowledge could be better integrated into policy making and regulation (e.g. Schmaltz et al., 2024).

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1.3 Status and Role of Soil Biodiversity

The current status and trends in soil biodiversity across Europe are poorly known. EJP SOIL projects focused on modelling and mapping soil biodiversity patterns and functions across Europe, and on the soil microbiome in the rhizosphere and on symbiotic microorganisms or inoculated microorganisms (e.g. Oberholzer et al. 2024).

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2. Climate change mitigation

Soils represent the largest terrestrial reservoir of organic carbon and the balance between soil organic carbon (SOC) formation and loss is expected to drive powerful carbon-climate feedbacks. Agricultural soils have lost huge amounts of organic C since the advent of agriculture and continue losing C in many European locations. Preserving current soil organic carbon stocks and increasing them in agricultural soils, in addition to the effective reduction of N2O and CH4 emissions from agriculture, required progress in five areas:

- Understanding the mechanisms and drivers behind C sequestration in soils and GHG emissions from agricultural soils.
- Evaluating the effect of individual and combined soil management options on C sequestration in soils and GHG emissions and providing realistic estimates for SOC storage potential across EU agricultural soils.
- Identifying, understanding and predicting trade-offs between C sequestration and GHG emissions from agricultural soils.
- Measuring, reporting, and verifying (MRV) SOC stocks and GHG emissions.

A large number of projects were developed on this theme: CarboSeq, MixRoot-C, MaxRoot-C, INSURE, TRACE-Soils, SOMMIT, EnergyLink, AgroEcoSeqC, EOM4Soil, STEROPES, Probefield, Freacs, SIC-SOC-DYN, C-arouNd, TilSoilC, CarboGrass, SOMPACS, TRUESOIL, ICONICA.

2.1 SOC sequestration understading

Among the standing questions in the field are the contribution of below-ground C (roots and rhizodeposits) to SOC stocks, the role of plant cover diversity on SOC accrual and stabilisation and C and N dynamics (e.g., Martins et al 2024). Microbial carbon use efficiency (e.g. Bolscher et al. 2024), plant soil synchrony in nutrient cycles (e.g. Fontaine et al. 2024), priming (e.g. Schiedung et al. 2023) and saturation of SOC stocks (e.g. Begill et al. 2023) were also addressed.

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2.2 SOC sequestration Potential

Accurate and reliable estimates of the C sequestration potential in soils are essential at the national scale, for countries to set their own targets and commitments in the framework of the Paris Agreement and vis-à-vis the EU Climate Law. Furthermore, implementation of C farming at the farm scale requires robust estimates of this potential. While only a few countries estimated their national C sequestration potential in agricultural soils (e.g. Bamière et al. 2023, Budai et al. 2024), they did it with heterogeneous methodologies as demonstrated in Rodrigues et al. (2021). A comprehensive assessment was hence missing for agricultural European soils on how much soil organic carbon (SOC) can be sequestered, and this assessment was undertaken while diversification of the plant cover, use of exogenous organic matters, reduced tillage, conservation agriculture and organic agriculture were investigated using long term experiments (e.g. Fohrafellner et al. 2024). SOC stock accrual estimates were derived for European countries, that allow to simulate and estimate the effect of implementing such management options on the evolution of national or European agricultural SOC stocks with a Tier 2 approach (https://shinyapp.cra.wallonie.be/ejpsoil-carboseq/).

Peer-reviewed Articles
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Deliverables and Reports
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2.3 Tradeoffs SOC - N-P

An additional storage of organic C in soils may be associated with nitrogen and phosphorus leaching, thereby decreasing water quality, or additional N2O or methane emissions thereby increasing GHG emissions. Such trade-offs were quantified in organic soils when rewetting peatlands (e.g. Koch et &l. 2023), and in mineral soils when implementing conservation agriculture or applying exogenous organic matters (e.g. Valkama et al. 2024) and tools were developed to estimate them (e.g. Calone et a., 2024).

Peer-reviewed Articles

Policy briefs and Notes

Deliverables and Reports

Datasets

Webinars & Educational Materials

Peer reviewed articles

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2.4 MRV Methodology

Sensing tools, either remote sensing or proximal sensing are being developed and used as low cost and high throughput methodologies for collecting information on soil carbon contents. These methods are emphasized in the EU Soil strategy and are increasingly being used in Measuring, reporting and verification for carbon farming schemes. However, their limitations and domains of validity were insufficiently established (e.g., Knadel et al. 2022). Modelling the evolution of SOC stocks is also central to MRV.

Peer-reviewed Articles
Policy briefs and Notes
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3. Climate change adaptation

Adaptation refers to changes in human and natural systems in response to actual or expected climatic change and its impacts. EJP SOIL investigated climate changes, including extreme events effects on agricultural soils within several research projects (CLIMASOMA, SoilX, ARTEMIS, SoilSalAdapt).

3.1 Management options evaluation

Soil, crop, and water management at the field and farm levels are studied and modelled to understand how management practices affect soil functions under both current and future climatic conditions (e.g. Blanchy et al. 2023; Coucheney et al. 2024). This understanding helps in developing adaptation measures and strategies.

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4. Soil Information Assessing & Monitoring

As soil is a non-renewable resource, having consistent and accessible information about its condition is essential to prevent soil degradation and support evidence-based policies that promote soil health restoration and sustainable soil management. Within this context, eight EJP SOIL research projects (SIREN, SERENA, MINOTAUR, SenRes, STEROPES, Probefield, FAMOSOS, SOIL-ES), along with a dedicated EJP SOIL work package (WP6), have significantly contributed to the harmonization, organization and storage of soil-related knowledge. During the timeframe of the EJP SOIL programme, the European soil landscape evolved significantly after the launch of the European Soil Observatory (EUSO) in 2021 and of the Mission Soil, the proposal of the Soil Monitoring and Resilience Directive (European Council, 2024) and the prospect of new ESA satellites in 2028.

4.1 Framework & Indicators

Assessing soil health necessitates agreement on its definition and its quantification with relevant soil health indicators (e.g. Faber et al. 2023). Indicators are assessed using target and/or threshold values, which define achievable levels of the indicators or functions (e.g. Matson et al. 2024).

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4.2 Innovation and Methods for data acquisition

In recent years, soil sensing technologies (both proximal and remote) have emerged as a promising solution to speed up and reduce the cost of soil surveys. The current performance of proximal sensing techniques for soil property estimation was evaluated, including the effect of different spectral transformation, model calibration and transfer approaches for soil property estimation using existing soil spectral libraries (e.g. Metzger et al. 2023). SOC content prediction using remote sensing has been improved using temporal mosaics from time series, available information on soil texture, and accounting for soil moisture (e.g. Urbina-Salazar et al. 2021).

Peer-reviewed Articles
Policy briefs and Notes
Deliverables and Reports
Datasets
Webinars & Educational Materials

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4.3 Harmonised soil information, data and monitoring systems

While Europe is relatively data rich, the existing soil information is not harmonized and little shared on national and INSPIRE portals by public institutions (e.g. Cornu et al. 2023, Fantappie et al. 2021). A draft general agreement for specific data sharing has been proposed, as well as a metadata catalogue of soil datasets and subsequent workflow, guidance and tools to harvest and provide such metadata of soil datasets (https://catalogue.ejpsoil.eu/collections/metadata:main/items). Soil monitoring systems across countries studied differ in sampling designs, protocols, analytical methods, and revisit frequencies (Bispo et al. 2023; Froger et al., 2024; Meurer et al., 2024) which can lead to non-comparable data at national and international levels.

Peer-reviewed Articles

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Peer Reviewed Articles

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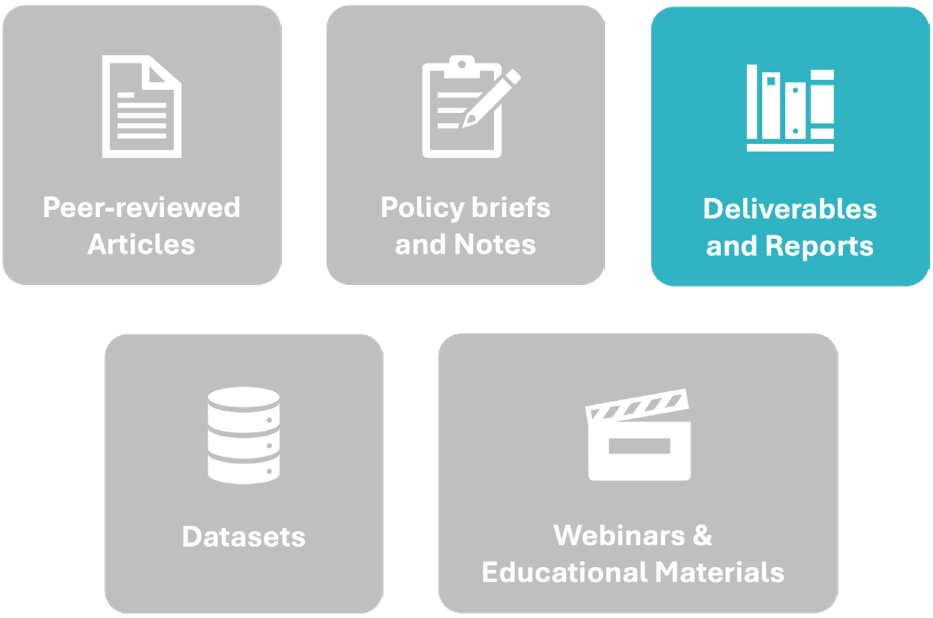
5. Fostering adoption

Adoption of sustainable soil management options is currently low in Europe (e.g. Heller et al. 2024). Factors limiting adoption of a given management option can be biophysical, but many are socio economic: availability of the knowledge and lack of adequate technical advice, economic constraints and lack of incentives and efficient policies and farming perceptions and traditions (Vanino et al. 2023, Thorsøe et al. 2023). The EJP SOIL programme focused on the science to policy interface and ways to foster adoption. Topics that helped stimulating the knowledge application were for example the evaluation of available tools and available methods for stakeholder engagement and for creating incentives. Projects concerned were in particular iSOmPe, Road4Schemes, SIMPLE, PRAC2LIV, Into-Dialogue and BioCASH and the activity of a dedicated work package.

5.1 Support tools evaluation

To make decisions about soil management that are conducive to soil health, land managers and other stakeholders need reliable information and appropriate tools. Decision Support Tools (DSTs) may serve multiple functions e.g., practical decision making, registration, and monitoring. Substantial differences exist in current fertilisation guidelines across Europe, in the content, in soil test methods and how crop nutrient requirements are calculated, in the format and in their delivery (Higgins et al. 2023).



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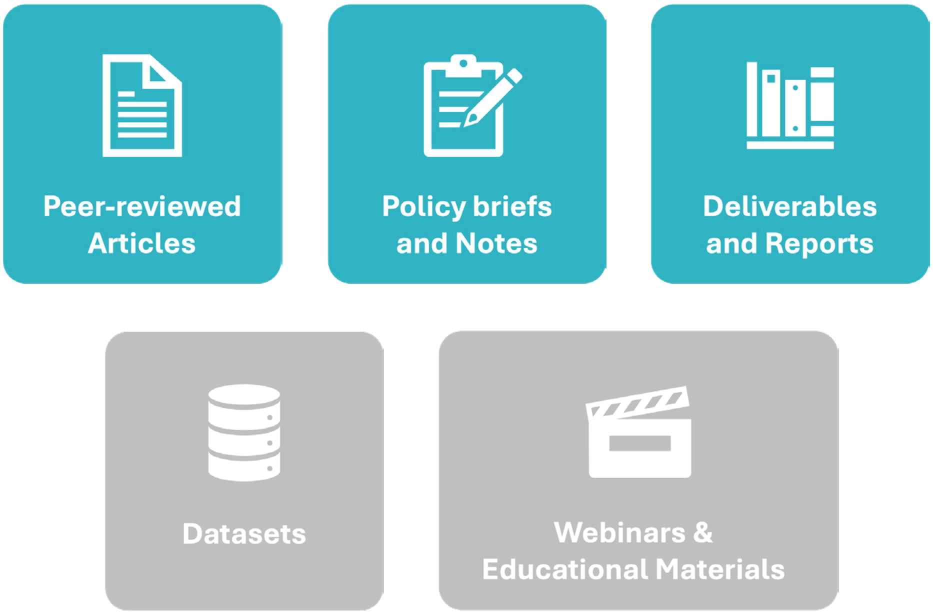
5.2 Tools for stakeholder engagement

Stakeholder engagement is crucial, in various instances and arena, to foster use of existing soil knowledge, development of new soil knowledge and implementation of sustainable management of agricultural soils. Stakeholder consultations (e.g., Vanino et al. 2023, Thorsøe et al. 2023, Heller et al. 2024) allows to identi. Citizen science indeed raises awareness among participating stakeholders and contributes to develop soil knowledge (Mason et al. 2024). There is a need, however, to institutionalise soil health science- policy- practice interfaces, such as done in the EJP SOIL National Hubs (Visser et al. 2023).



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5.3 Incentives and policy evaluation

The EJP SOIL concentrated on existing European policies (e.g., Farm2Fork strategy), on policies under development (Carbon Removals and Carbon Farming Regulation, Soil Monitoring and Resilience Directive) as well as on existing incentives, such as carbon faming schemes). Economic incentives for C sequestration, i.e. carbon farming schemes were inventoried and analysed, which allows to drive recommendations (e.g. Cruiscoli et al. 2024). Scenario modelling helps assessing the effect of policies or monitoring the policy goals set (e.g. Farm to Fork goals for 2030 and 2050).

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Policy briefs and Notes

Deliverables and Reports

Datasets

Webinars & Educational Materials

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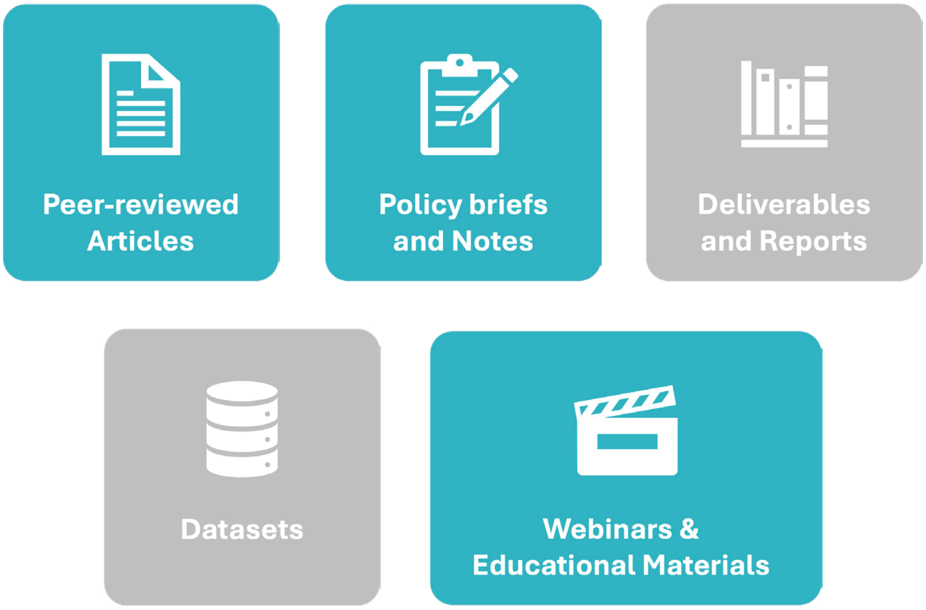
5.4 Capacity building and education

Sustainable and climate smart management of soils requires human and institutional capacity, expertise and competencies in soil science and agronomy. Soil science related expertise will be more and more in high demand to serve academic, policy and practices of the European Green Deal, the EU Soil Strategy for 2030 and the proposed EU Directive on Soil Monitoring and Resilience. The established baseline of soil science in higher education (Barron and Villa, 2022) was complemented with an analysis of skills needed in the future for fostering sustainable soil management, and of related professional profiles (Veenstra et al. 2024, Walter et al. 2024).



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