A review of standards for measuring soil organic carbon

Implementing the Soil Monitoring and Resilience Directive for healthy forest soils

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Authors

- Martina Forbicini, Programme Officer - ECOS martina.forbicini@ecostandard.org
- Lukas Huhn, ECOS expert lukas.huhn.ecos@posteo.de
- Samy Porteron, Senior Programme Manager - ECOS samy.porteron@ecostandard.org

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Executive summary

- **Healthy soils** underpin resilient forest ecosystems, providing key ecosystem services, including carbon sequestration.
- **Soil Organic Carbon (SOC) measurement methods** vary and must be carefully assessed to ensure consistent monitoring and comparability of soil health across the EU.
- The EU's recently **adopted Soil Monitoring and Resilience Directive** ('Soil Monitoring Law') holds potential for addressing some gaps in forest soil health monitoring created by the lack of an agreement on an EU Forest Monitoring Law.
- This paper provides a **qualitative review of a selected list of SOC standards** to support the implementation of the Soil Monitoring and Resilience Directive, which will be key for collecting data to monitor the status of soil health and the capacity of soils to act as carbon sinks.
- The updated standard EN 15936:2022 broadens ISO 10694 (currently referenced in the Soil Monitoring Law) to cover multiple matrices, and strengthens calibration, quality-control, and sample-treatment requirements, improving consistency across laboratories, enhancing harmonisation and comparability of carbon measurements.

Key recommendations

- Member States should adopt fit-for-purpose SOC measurement methods aligned with monitoring goals and soil types, namely
    - **EN 15936:2022 Soil, waste, treated biowaste and sludge - Determination of total organic carbon (TOC) by dry combustion** is the most established method for total SOC, but it requires laboratory-intensive procedures.
    - **EN 15935:2021 Soil, waste, treated biowaste and sludge - Determination of loss on ignition (LOI)** is simple and low-cost but provides limited carbon fraction detail and weak comparability.
    - **EN 17505:2023 Soil and waste characterization - Temperature dependent differentiation of total carbon (TOC400, ROC, TIC900)** offers detailed SOC fraction information with good accuracy, suitable for well-resourced specialised laboratories.
    - **EN ISO 17184:2014 Soil quality - Determination of carbon and nitrogen by near-infrared spectrometry (NIRS)** provides rapid, non-destructive, potentially in-field measurements but rely on robust calibration and advanced equipment; simultaneous measurement of total nitrogen and carbon-to-nitrogen ratios.
- **Revise SOC measurement standards** (such as EN ISO 17184), to incorporate recent technological advances.
- **Standardise non-standardised SOC methods** to improve comparability across Member States.
- **Support remote sensing and emerging technologies** for SOC monitoring, ensuring all **calibration and validation** data are **based on standardized** in-situ measurements.

Aim of this paper

This paper qualitatively reviews a select group of standards for measuring soil organic carbon, including those contained in the Soil Monitoring and Resilience Directive's Annex II, in support of its implementation. As the focus of this review is on forests soils, **soil organic carbon** proves to be a very interesting indicator as it has very high relevance to forests ecosystem health and is central to ongoing policy debates. The aim of the paper is twofold: to provide guidance to Member States on which methodologies to choose for measurement of soil organic carbon and to provide support to the European Commission, in its empowerment to adopt delegated acts to amend Annex II, Part B in order to adapt the reference methodologies to scientific and technical progress.

Healthy soils as the foundation of resilient forest ecosystems

Despite being hidden from view, **healthy soils are the foundation of resilient forest ecosystems** and a crucial tool in tackling the climate crisis. Healthy soils are the basis for healthy trees, shrubs and grasses that populate forests, thanks to several characteristics. First, soils are habitats to microbes, bacteria, fungi, and other decomposers which play a necessary role in plant growth. By breaking down organic matter, soil biodiversity enables the cycling of fundamental nutrients - such as nitrogen, phosphorus, and potassium - which enhances forest productivity. Second, the structure of soils contributes to water retention and regulation, supporting not only plant growth, but also **flood prevention and erosion control**. Forest soils also filter and trap pollutants and sediments while helping sustain water quality in streams, rivers, and groundwater sources.

Soil is an essential but overlooked element of the climate system

Forest soils play a critical role in **combatting both the causes and the consequences of climate change**.[1] Functions such as carbon sequestration and climate regulation are all highly dependent on soil organic matter - the organic residues, e.g. leaves or roots found in soils in various stages of decay.[2] As a result of the decomposition of organic matter derived from plants, roots, and microorganisms[3], some carbon is stored in the soil[i] - soil organic carbon (SOC) - while some is naturally released into the atmosphere as greenhouse gases. This decomposition is a continuous process driven by soil biological activity which results in distinct SOC fractions – different categories of organic carbon. Some parts are fresh and decompose quickly, while others are old and very stable. These fractions differ in functions and stability depending on conditions such as temperature, soil moisture and land management practices.[4]

Healthy soils that are rich in organic matter content **sequester large amounts of carbon** (on average, SOM consists of approximately 58% carbon)[5] and help to mitigate climate change by reducing atmospheric carbon dioxide levels.

Forest soils are massive reservoirs of carbon

Soils host the largest carbon pool in terrestrial ecosystems.[6] **Forest soils are the largest reservoirs of terrestrial carbon,** containing 80% of global terrestrial carbon and 70% of the soil organic carbon.[7] Within forests, soils represent an estimated 44% of all carbon stored compared to the above-ground vegetation[8] - albeit with differences depending on forest types, with boreal and old-growth temperate forests storing the most carbon in their soils.

[i] Soil carbon refers to carbon stored in soils, which exists in both organic and inorganic forms.

Soil absorbs a lot of carbon if treated well, but it can also lose it. When the soil is exposed to precipitation, as well as increasing temperatures or other elements, this leads to organic matter decomposition and the release of greenhouse gases in the atmosphere.[9] Poor soil management – including destructive clear cutting, intensive monoculture, and the use of heavy machinery - deteriorates the capacity of soils to sequester and retain carbon, as shown in Figure 1.

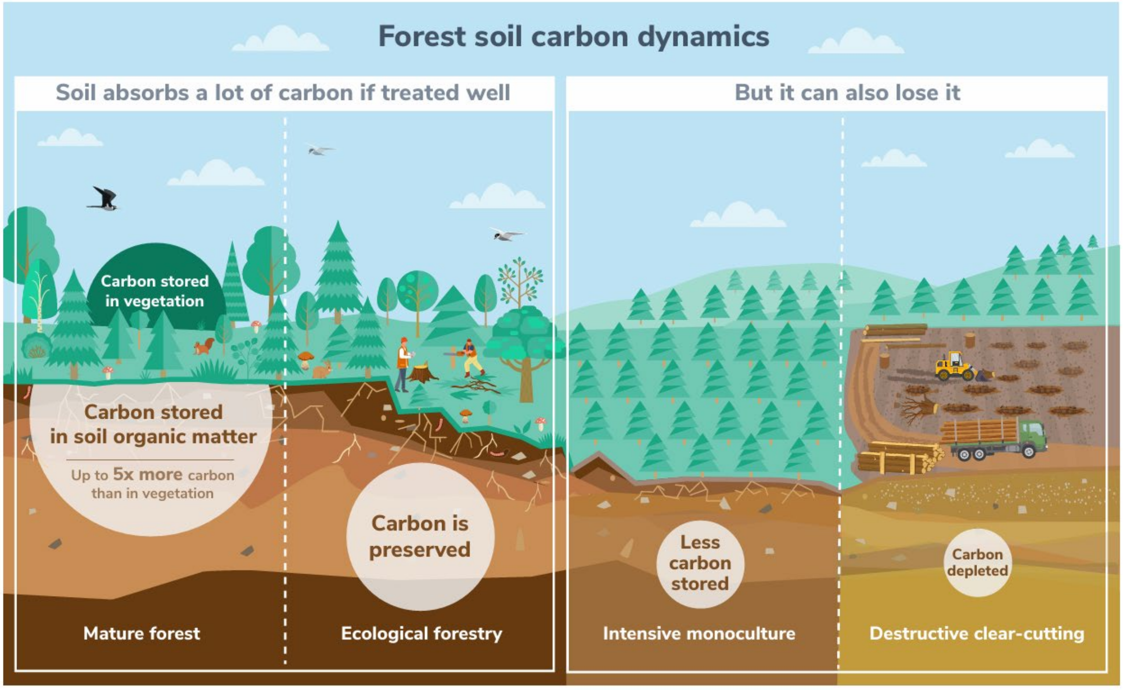

Figure 1: Forest soil carbon dynamics.
ECOS (2023) Seeing the forest through the trees: How sustainable timber buildings can help fight the climate crisis

Alarming degradation of EU soils

Alarmingly, **60-70% of EU soils are undergoing degradation** processes.[10] The loss of organic carbon stored in soils, alongside erosion and biodiversity decline, are among the main reasons for this classification.[11] Soil degradation threatens the provisioning of ecosystem services that are essential for ecosystems functioning and for human wellbeing. The greatest impacts of forestry on soils occur by physical disturbance during drainage, planting, and harvesting, with risks of soil erosion, compaction, nutrient removal, and soil water changes[12]. Forests cover approximately 39% of the EU's total land area[13] and more than 35% of European forest soils are considered degraded[14], it is therefore **vital to rethink how we manage forests to minimise soil disturbance**. This includes applying sustainable soil management and **monitoring the key dimensions of soil health** in forests to ensure that the fundamental role soils play is not impaired, especially when it comes to carbon sequestration.

Harmonised soil monitoring and assessment, through robust methodologies, is fundamental to provide reliable data and information that can be used to inform realistic policy and strategic action.

Soil carbon in EU governance

Due to their ability to capture and store carbon, healthy forest soils contribute to the achievement of the EU's objectives on climate change. The revised Regulation on Land Use, Land Use Change and Forestry (LULUCF) not only places soil carbon central to the achievement of targets on the pathway to a climate neutral Europe, but also calls for Member States to prepare a system for the monitoring of soil carbon stocks, using, inter alia, the land use/cover area frame statistical survey (LUCAS) dataset.

The European Commission's Communication on Sustainable Carbon Cycles underlines the need for clear and transparent identification of the activities that unambiguously remove carbon from the atmosphere such as the development of an EU framework for the certification of carbon removals from natural ecosystems including soils[ii], within the Carbon Removal Certification Framework (CRCF).

Furthermore, following on the objectives of the EU Forest Strategy for 2030, in November 2023, the European Commission proposed a **Regulation on a monitoring framework for resilient European forests** (also known as *Forest Monitoring* Law or *FML*). The proposed FML aimed at improving the health and resilience of EU forests by harmonising the collection of forest ecosystem and economic data. Unfortunately, negotiations on the file had drastically weakened it[iii] and it ultimately repealed.

Nevertheless, the recently adopted Soil Monitoring and Resilience Directive (also known as *Soil Monitoring Law* or *SML*)[iv] still holds potential for filling some of the gaps in addressing forest soil health[v] that the lack of an agreement on an EU Forest Monitoring Law have created. Measures apply to all soils – agricultural, forest, urban. Many indicators are particularly relevant to forests, including: loss of soil organic carbon, soil compaction, soil contamination, acidification, reduction of soil water retention and infiltration. Although the SML has been scrapped of its core measures and has a rather low level of ambition, it is still a key step in creating a coherent EU monitoring framework and a harmonised approach to assess soil conditions across Europe with coordinated indicators and values[vi].

Additionally, acknowledging the vital role of forests, the EU has introduced landmark frameworks like the Nature Restoration Regulation (NRR) that can support advancing both soil and forests monitoring, reducing their degradation, fostering restoration and promoting sustainable use.

Policy alignment and choice of measurement methods are key to ensure that these policies can collectively reshape current and future forest management regimes across the EU.

[ii] Read more, ECOS position Improving the EU CRCF methodologies
[iii] Read more, ECOS position Hatchet Job on the Forest Monitoring Law – What Next?
[iv] Read more, joint press release European Parliament seals the deal on first EU soil law
[v] Read more, ECOS position Towards robust EU Forest Monitoring: Indicators for forest health, resilience, and functions - ECOS
[vi] Read more, joint recommendations: NGO recommendations for trilogue negotiations on the Soil Monitoring Law and our joint statement at The urgent need to adopt the EU Soil Monitoring Law - ECOS

Measuring soil organic carbon in the Soil Monitoring and Resilience Directive

The SML defines "**soil health**" as "the physical, chemical and biological condition of the soil determining its capacity to function as a vital living system and to provide ecosystem services"[vii]. While **Annex I** provides a list of soil indicators to be monitored by Member States, **Annex II** contains the methodologies to measure each soil indicators.

Loss of soil organic carbon as shown in SML Annex I: indicators

For the degradation aspect **loss of soil organic carbon (SOC)**, Annex I (as shown in figure 2) lists the following soil indicators (referred to as "descriptors").

Figure 2 – Soil Monitoring Law indicators/descriptors

Aspect of soil degradation	Soil descriptor	Criteria for healthy soil condition – nonbinding sustainable target values	Land areas exempt from meeting the related criterion
Part A: soil descriptors with criteria for healthy soil condition established at Union level			
Loss of SOC	SOC concentration (g per kg)	**Organic soils**: respect targets set at national level, in accordance with Article 4(2) and (4), and Article 11(4) of Regulation (EU) 2024/1991.	No exemption
		Mineral soils: SOC/Clay ratio > 1/13.[viii] Member States are expected to apply corrective factors to the ratio where specific soil types or climatic conditions justify it, accounting for the link to structural stability.	Non-managed soils in natural areas
Part B: soil descriptors with criteria for healthy soil condition established at Member States level			
Loss of SOC	SOC stocks (tC ha-1)	Contribute to national targets for net greenhouse gas removals in the LULUCF sector as referred to in Article 4(3) of Regulation (EU) 841/2018.	No exemption
	Optional: SOC content (g per kg)	> "minimum value", which shall be laid down by the Member State by soil texture.	

Soil Organic Carbon (SOC) concentration (Part A) is a widespread soil indicator correlated with soil health. Higher SOC concentration usually results in improved soil functions and conditions, such as soil aggregation, nutrient supply, and water retention.

Soil organic carbon stocks (Part B) is a high relevance indicator in carbon modelling and accounting, but it does not represent a stand-alone soil quality indicator. It reflects an estimated total amount of carbon stored in soil across an area and depth. SOC stock is calculated based on SOC concentration, bulk density and soil depth, often accompanied by meta-data such as land management.

[vii] Article 3(4)
[viii] Ratio of SOC content to the content of the clay fraction (fraction with a diameter < 0.002 mm).

Loss of soil organic carbon as shown in SML Annex II: methodologies

Annex II, (as shown in figure 3), provides the following reference methodologies for determining or estimating the values of soil organic carbon:

Figure 3: SML Annex II: Part B: Methodology for determining or estimating values of soil descriptors

Soil descriptor	Reference methodology	Minimum methodological criteria	Validated transfer function required?[ix]
Soil Organic Carbon (SOC)	ISO 10694 Determination organic carbon and total carbon after dry combustion, ensuring all carbon is incinerated. SOC shall be calculated by determining the total carbon content and subtracting the carbon present as carbonate, which shall be determined in accordance with ISO 10693.	Not applicable	Yes
Soil Organic Carbon Stocks (SOC stocks)	Methodology as set out in Annex V of Regulation 2018/1999 in accordance to the 2006 IPCC Guidelines for National GHG Inventories.	Not applicable	Yes

Flexibility is given to Member States in choosing the methodology that best suits their needs. In fact, when a reference methodology is set out in the table, either of the following are to be used:

- The reference methodology.
- A methodology equivalent to the reference methodology.
- Another methodology, provided that it is available in the scientific literature or publicly available and a validated transfer function[x] is available.

If a CEN methodology is available, it is preferred over the reference methodology. In this case the initial reference methodology is considered as an equivalent methodology.[xi]

Scope of the review

The following available EN and EN/ISO standards for methods to measure Soil SOC concentration are included in the review:

- **EN 15936:2022** - Soil, Waste, Treated Biowaste and Sludge. Determination of Total Organic Carbon (TOC) by Dry Combustion (expected to be merged[xii] with **ISO 10694** "Soil quality - Determination of organic and total carbon after dry combustion (elementary analysis)").
- **EN 15935:2021** – Soil, waste, treated biowaste and sludge - Determination of Loss on Ignition (LOI).
- **EN 17505:2023** – Soil and waste characterization - Temperature dependent differentiation of total carbon (**TOC400**, **ROC**, **TIC900**).
- **EN/ISO 17184:2014** – Soil quality - Determination of Carbon and Nitrogen by Near-Infrared Spectrometry (NIRS).

[ix] (if using a methodology different from the reference methodology)
[x] A validated transfer function is a mathematical relationship (often a regression or calibration model) that links the results of a proxy method to those of a reference method defined in a standard.
[xi] Soil Monitoring and Resilience Directive, Annex II, Part B
[xii] EN ISO 15936 - a merger of ISO 10694 and EN 15936 - is expected, leading to the withdrawal of ISO 10694 and thus making reference to ISO 10694 outdated.

ISO 10693 "Soil quality - Determination of carbonate content - Volumetric method" is mentioned in the SML Annex II as a reference methodology to measure Soil Organic Carbon (SOC), however, it is **not within the scope of this review** as it only measures inorganic carbon. The carbonate content of soil is an important additional parameter to determine inorganic carbon (IC), which can be subtracted from total carbon (TC) to infer the organic carbon (OC) content. This standard is typically used in calcareous soils (high in carbonates).

Criteria and sub-criteria for the review

We used a set of practical criteria – along with associated sub-criteria – to guide the review. The criteria were chosen with the objective of identifying the methods that are not only scientifically sound but also suitable for routine monitoring and soil health assessment programmes across diverse European contexts. We evaluated each criterion and sub-criterion by defining appropriate scales that allowed for a **comparative scoring** of the methods. The scores for each criterion were calculated by averaging the sub-criteria scores and rounding down the result to the nearest whole number. These scores were used to compare the strengths and weaknesses of the abovementioned methods.

It should be noted that this paper represents an **indicative review** rather than a comprehensive scientific assessment. The analysis focuses on a **selected subset of standards**, which does not constitute an exhaustive list. Additional methods - particularly those not yet standardised, but described in the scientific literature or peer-reviewed studies - could be incorporated in future work. Furthermore, the review has several methodological limitations: it does not include statistical error thresholds, uncertainty quantification, or experimental validation of each method. Finally, while the comparability of results, across methods and laboratories, especially where results are intended to be used to monitor change over time, is an important consideration, it lies outside the scope of this review.

Criterion 1: Relevance

This criterion assesses how often the method is used in European soil monitoring programs, whether it provides additional knowledge to achieve healthy soils, and how widely it is recognised and supported in scientific literature in the past 10 years.

- Relevance in European soil monitoring systems:
    - Based on recent literature with focus on European soil monitoring systems.
    - Scale: 0 (no relevance), 1 (low relevance), 2 (moderate relevance), 3 (high relevance)
- Relevance for soil health assessment:
    - Does the standard provide additional parameters relevant for soil health assessment, such as nutrient ratios and carbon fractions?
    - Scale: 0 (no relevance), 1 (low relevance), 2 (moderate relevance), 3 (high relevance)
- Relevance in scientific literature:
    - Based on a web-of-science research analysing the frequency of use of the method over the past 10 years.
    - Scale: 0 (no relevance), 1 (low relevance), 2 (moderate relevance), 3 (high relevance)

Criterion 2: Robustness and accuracy

Considering the diversity of European soils, this criterion evaluates the method's reliability and precision across different soil types, environments, and laboratories.

- Reliability across different soil types and contexts:
    - Based on comparability across different soil samples and inconsistencies – such as sensitivity to interfering substances - reported in the standard.
        - Scale: 0 (not reliable), 1 (low reliability), 2 (moderate reliability), 3 (high reliability)
- Variability across different laboratories:
    - Based on performance characteristics in interlaboratory comparison studies[xiii] reported in the standard.
        - Scale: 0 (no information), 1 (high variation), 2 (moderate variation), 3 (low variation).
- Direct measurement vs. indirect estimation of SOC:
    - Based on a review of the measurement principles and procedures described in the standard.
        - Distinct categorical scale: 0 (indirect estimation), 1 (indirect measurement with a conversion factor), 2 (semi-direct measurement using a calibration function), 3 (direct measurement of SOC).

Criterion 3: Feasibility and ease of use

The practicality of applying the method in routine monitoring is examined under this criterion, including cost, equipment needs, time requirements, and laboratory availability.

- Equipment demand and costs:
    - Based on the devices and reagents needed.
    - Scale: 0 (no information), 1 (high demand), 2 (moderate demand), 3 (low demand)
- Time and workload:
    - Time required and laboratory effort (including number of samples per day, steps) based on analysis of procedure and experience reported in literature which applied the standard.
    - Scale: 0 (no information), 1 (high effort), 2 (moderate effort), 3 (low effort)
- Availability of laboratories:
    - Based on a web search for laboratories in Europe that offer this standard. Combined with further availability indicators, such as the frequency of the method in scientific publications and in EU monitoring programs.
    - Scale: 0 (no information), 1 (low availability), 2 (moderate availability), 3 (high availability)

Criterion 4: Environmental impact

This criterion considers potential effects of the method on the environment, with a focus on soil disturbance, use of hazardous materials, and overall energy or resource demand.

- Prevention of soil disturbance:
    - Based on the type of sampling needed.[xiv]
    - Scale: 0 (no information), 1 (high disturbance), 2 (low disturbance), 3 (no disturbance).
- Use of hazardous materials and energy demand:
    - Based on the devices and reagents used.
    - Scale: 0 (no information), 1 (low), 2 (moderate), 3 (high).

[xiii] Studies tend to use prepared samples for comparison, but sample preparation introduces significant variability and often differs between laboratories

[xiv] Representative individual samples which require the removal of soil layers cause higher disturbance; mixed samples based on multiple small drillings. In field direct sensor-based measurement and remote satellite-based estimation causes no disturbance.

Strengths and weaknesses of reviewed standards

The following chapter provides a summary of the findings based on the above set criteria and sub-criteria. Table 1 shows a summarised score for each standard in the criteria described above. A detailed breakdown, with additional information, is found in detailed analysis.

Table 1: A summarised score per standard's criterion

EN ISO Standard	Relevance	Robustness & accuracy	Feasibility & ease of use	Environmental impact
	1=low, 2=moderate, 3=high			1=high, 2=moderate, 3=low
EN 15936:2022 Determination of total organic carbon (TOC) by dry combustion	2	3	2	2
EN 15935:2021 Determination of loss on ignition	1	1	3	2
EN 17505:2023 Temperature dependent differentiation of total carbon (TOC400, ROC, TIC900)	1	2	1	2
EN ISO 17184:2014 Determination of carbon and nitrogen by near-infrared spectrometry (NIRS)	2	2	2	2

EN 15936:2022 – Soil, Waste, Treated Biowaste and Sludge. Determination of Total Organic Carbon (TOC) by Dry Combustion

In this method, soil samples are combusted at high temperature in oxygen, converting soil carbon to CO_2. The amount of CO_2 released is directly measured to quantify total carbon. There is an indirect and a direct method for SOC quantifications. In the indirect procedure, the SOC is determined by the difference of total carbon and total inorganic carbon, which is separately measured from a sub-sample. For the direct measurement, the inorganic carbon is removed previously to the dry combustion. Unless inorganic carbon is removed prior to analysis, the results will be for total carbon. The need for removal or separate analysis of SIC introduces a risk of error, which is often overlooked because most analysis is done on soils with low SIC. In places where SIC is significant, this can be critical issue for this method's validity to only measure SOC. The additional application of ISO 10693 "Soil quality - Determination of carbonate content - Volumetric method" is necessary.

EN 15936:2022 is the most widely adopted SOC measurement in European soil monitoring systems. It offers general and no additional soil health information but is well established in scientific literature from the past 10 years. The method exhibits high robustness and comparability across soil types, though high carbonate soils present challenges. Variation among laboratories is very low. This technique allows both direct and indirect SOC measurement but requires specialised, costly equipment and various reagents. The analysis takes about one day with moderate throughput. The availability of equipped labs is good. The sampling approach can be handled with relatively low soil disturbance, but environmental impact is higher compared to other methods due to reagent use and energy demands.

EN 15936:2022 expands the scope of ISO 10694 "Soil quality - Determination of organic and total carbon after dry combustion (elementary analysis)" beyond soils to include waste, sludge and treated biowaste, and updates calibration, quality-control and sample-treatment requirements.

Moreover, the procedural decision-tree in EN ISO 15936 is stricter and more transparent, improving comparability and reducing ambiguity in how labs process different sample types.
These changes harmonise dry-combustion carbon determination across a wider range of environmental matrices and improve comparability of data.

- Overall, this method is equivalent to the standard referenced in the SML. It is the most established and robust method for total SOC measurement but requires more complex and lab-intensive operations.

EN 15935:2021 – Soil, waste, treated biowaste and sludge - Determination of Loss on Ignition (LOI)

This method measures SOC indirectly by heating soil samples to burn off organic matter. The weight loss after ignition corresponds to organic carbon content, estimated via a conversion factor. It is a simple thermal decomposition approach.

The LOI method, described in EN 15935:2021, has been used in some European soil monitoring programs in the past years[15] and is frequently cited in scientific literature, but it presents low relevance for soil health and monitoring. While it reflects the general correlation between SOC and soil health, there is no further insight into soil condition from this method. The method's robustness and accuracy score is low. Differences in national temperature protocols and the influence of carbonate content and soil texture reduce comparability. Interlaboratory variability is moderate compared to other methods. The procedure involves indirect SOC estimation via weight loss and conversion factors, requiring low-cost equipment and no hazardous reagents, although energy consumption is relatively high due to oven use. The analysis duration is around 1-2 days with moderate number of samples per day, thanks to possibility of batch analysis and benefits from good laboratory availability. Soil disturbance is relatively low due to mixed sampling, depending on the scope of the analysis.

- Overall, this method stands out for simplicity and low cost, but lacks detailed carbon fractionation and comparability.

EN 17505:2023 – Soil and waste characterization - Temperature dependent differentiation of total carbon (TOC400, ROC, TIC900)

This method measures different SOC fractions by sequential heating to specific temperatures. CO_2 released within each temperature range is allocated to different carbon fractions:

- TOC400 (100–400°C): total organic carbon which is released up to 400 °C.
- ROC600 (400–600°C): residual oxidizable carbon measured at 600°C.
- ROC900 (400–900°C): residual oxidizable carbon measured at 900°C.
- TIC900 (640–900°C): total inorganic carbon which is released up to 900°C.

Currently, this relatively new standard sees limited application in monitoring systems and scientific literature. The method shows promising robustness with relatively low variability between labs, though high concentrations of substances might disturb measurement and can cause interferences. Some carbonates or carbonate mixtures can lead to high errors, thus the additional application of ISO 10963 is necessary. Direct measurement of SOC fractions is a key advantage. However, the method has high equipment costs, is relatively complex, requiring specialised apparatus. Analysis duration is about one day with moderate throughput. Laboratory availability is moderate, primarily in specialised facilities. Mixed sampling limits soil disturbance, and reagent and energy usage is moderate resulting in a moderate environmental impact score.

- Overall, this method offers detailed SOC fraction insights with promising accuracy, suited for specialised labs with higher resource capacity.

EN ISO 17184:2014 – Soil quality - Determination of Carbon and Nitrogen by Near-Infrared Spectrometry (NIRS)

This method estimates carbon and nitrogen by analysing near-infrared light spectra reflected by soil. The absorption patterns correlate to organic compounds, and calibrated models translate spectra into SOC concentrations.

EN ISO 17184:2014 allows for direct simultaneous measurement of carbon and nitrogen, enabling carbon to nitrogen (C/N) ratio assessment relevant for soil health assessment. Gaining higher scientific attention since publication, its scientific relevance relative to the other methods has stabilized by now. The method is highly standardised but shows higher variability related to soil type, carbonate content, and calibration robustness. It involves semi-direct SOC estimation through calibration curves. High-tech, costly equipment with specialised apparatus is required. Once pretreated, multiple samples can be processed within a day, offering very low overall effort and potential field deployment. Currently, few laboratories explicitly offer this method, thus the availability is limited. The technique allows mixed sampling and in field measurements, minimizing soil disturbance. It benefits from low energy demand without reagent use, contributing to good environmental score.

- Overall, this method provides rapid, non-destructive measurements with an option for in-field analysis, but depends heavily on calibration quality and advanced equipment. In addition, it enables the parallel measurement of Total Nitrogen and C/N ratios, which are in the list of the soil indicators of the SML as well.

Conclusions

- For routine total SOC assessment, EN 15936 remains the state-of-the-art methodology.
- EN 15935 is the simplest method, but is not precise and accurate enough for a soil monitoring program across the diverse soil types in the EU. In case of choosing the loss on ignition method, it is crucial to closely adhere to the ISO EN 15935 method, as many national standards are working with different temperatures and duration times, hampering the comparability of results.
- For advanced functional carbon analysis, EN 17505 offers more possibilities.
- The emerging NIRS approach may facilitate fast, low-impact field measurements, pending wider adoption.

Choosing an appropriate method depends on monitoring goals, laboratory resources, desired data resolution, and environmental considerations. The evaluation of available EN and EN/ISO methods to measure SOC substantiates that different standards fit for different purposes. A fundamental point in the decision for a method depends on the scope and aim of the monitoring. As long as the purpose of the monitoring is not clearly defined, i.e. the limit or target values or the desired precision of the measurement, the decision remains unfounded and vague.

Moving forward

Based on the evaluation, we suggest the following for improvement:

- The NIRS standard EN ISO 17184 is from 2014 and the development of devices for lab and field analysis has been fast in the past 10 years. A timely revision of the standard could lead to a much better score in the evaluation and thus make this method a perfect fit for the SML.

- EN ISO 17505 is a relatively new method with a high potential. It is to be expected that this method will gain relevance in the coming years, e.g. via its application in research projects and publications. The SML bears the opportunity to include further aspects of soil organic carbon and its fractions[xv] in the monitoring and could benefit from the availability of this standard.
- **Satellite-supported remote sensing** is a rapidly developing field that may radically change the process of environmental monitoring and reporting[16]. The development of remote soil carbon assessment has been the focus of various research projects in the past years, but remote SOC assessment in forest soils remains challenging due to the vegetation cover. However, remote sensing is relying on calibration and validation of models and must always be accompanied by on-site measurements. Therefore, it would be a solid approach to already bear in mind whether the chosen method for SOC monitoring is adequate to support future remote monitoring schemes. The above presented evaluation and suggestions for improvement are applicable in this case.

Detailed analysis

- 2025-11_ECOS_SML-Annex-II-evaluation-of-methods

[xv] For example, parameters such as particulate organic matter (POM) or permanganate oxidisable carbon (POxC or active carbon) would be a valuable addition to the SOC indicators, as they give better indication on the quality of SOC fractions and their availability for microbial decomposition, which is key to understand the dynamics of SOC.

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