Umwelt Bundesamt

German Environment Agency

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Funding climate-friendly soil management – key issues

Determining the soil organic carbon (SOC) content and changes over time[1]

1 Background

Definition: Determining the content of soil organic carbon (SOC)[2] aims to quantify the present amount and the change over time of SOC in the soil of a set area.

Importance: Knowledge about SOC contents and their variation over a site and by time is crucial to determine the effectiveness of climate-friendly soil management practices.

Relevance: Determining total organic carbon in the soil and its variation over time shows the potential of a soil and management practice to be a sink for carbon, i.e. have carbon sequestration potential, or to be rather a source of CO_2 emissions. The ability to determine the carbon storage of soil (and any change) is a prerequisite for any results-based reward mechanism[3]. It is especially crucial for offsetting mechanisms[4], as any inaccuracy can lead to poor quality offsets that when used by other sectors result in more GHGs in the atmosphere.

2 Key issues

Determining soil carbon and soil carbon sequestration, i.e. the change of the carbon stock over time, faces the following challenges:

- **Slow soil carbon sequestration rates:** Sequestration is the difference of the carbon stock over time, usually shown as sequestration rate in tonnes per hectare per year. Sequestration can occur over long periods of e.g. more than 25 years for changes in tillage rotations and more than 30 years for grassland systems (West and Six 2007). Sequestration rates can differ greatly between sites and different management measures, for example, carbon sequestration of a degraded soil can be much higher than of soil close to saturation since degraded soils have a higher potential to capture and store even low carbon inputs, while soils close to saturation will need much additional input to store additional carbon. Carbon-rich soils close to saturation are also more exposed to mineralisation and loss of carbon due to higher microbial activity in fertile soils. Even when a saturation level is reached, potentially additional carbon can be sequestered by further changes in management, e.g. additional inputs or converting to reduced tillage, until the soil C storage capacity reaches its maximum saturation stage (West and Six 2007).

- **Low signal to noise ratio:** Relatively small changes in SOC over time (compared to baseline stocks) or high **soil heterogeneity** across areas may result in a high variance of the carbon

[1] This factsheet was also published as part of the UBA report "Funding climate-friendly soil management", available at http://www.umweltbundesamt.de/publikationen/Funding-climate-friendly-soil-management.

[2] A tonne of carbon is equivalent to 3.7 tonnes of carbon dioxide, i.e. 0.27t C = 1 t CO_2e.

[3] Results-based payment approaches make a payment dependant on the achievement and verification of a mitigation (or other environmental) result.

[4] Under offsetting approaches, the buyer is using the certificates for mitigation outcomes as a substitute for within value chain abatement or mitigation activities in their own sphere and counts it towards their own (voluntary) climate target.

stock measurements. If this variance is close to or greater than the expected SOC increases caused by the applied measures, measurement is very challenging.

- **Need for standardised procedures**, which are important to enable comparisons between different sites and management practices. This includes standardised sampling methods and laboratory analysis.
- **Other greenhouse gases:** The determination of soil carbon gives no direct information about emissions of other GHG, e.g. nitrous oxide, which can also be affected by climate-friendly soil measures.

Soil sampling and laboratory analysis

Soil carbon content is classically determined by soil sampling and analysis in a laboratory according to standard methodology. The most widespread approach is to determine the carbon content by dry combustion in an elemental analyser (Smith et al. 2019). The whole procedure including sampling, sample preparation and analysis requires a high number of samples due to soil heterogeneity; soil bulk density must also be calculated (Smith et al. 2019). To account for carbon changes in the soil, repeated measurements have to be applied over the same area, i.e. a sample must be taken before measures are implemented, which must then be repeated at regular intervals to measure how soil carbon has changed due to implementation of measures.

Key issues related to soil sampling and measurement:

- **Number of samples:** The total number of soil samples to describe an area depends on the site and heterogeneity of landscape, land use, management and land-use history. To calculate the change in the soil carbon stock due to a measure, sampling will have to be repeated after a certain time (e.g. five years).
- **Measurement depth:** Soil carbon determination is often restricted to the topsoil (30 cm), both by sampling and soil spectroscopy. This does not take into account shifts of carbon to deeper soil layers, e.g. by deep rooting plants, and long-term sequestration in depth. Sampling at multiple depths will increase the number of samples necessary. Carbon stocks in deep soil layers (> 60 cm) are more stable even after land use change (Guo and Gifford 2002). As long as microbial activity and carbon decomposition is not enhanced by fresh organic matter or soil turbation in depths, focusing the monitoring on shallower layers is justified (Fontaine et al. 2007).
- **Soil- and field-specific issues in sampling:** Sampling can be challenging when the soil is stony or has a high clay content and is dry. When field conditions (present management, topography) are suitable, a (semi-) mechanic device for sampling (e.g. a Nietfeld sampler attached to a tractor or a ramming core probe used with a jackhammer) may facilitate sampling in deep soil layers (> 50 cm). Manual sampling is still the method of choice because of machinery costs and field compaction reasons.
- **Labour and costs of soil sampling:** Determining SOC stocks is labour- and cost-intensive, due to the high number of samples over space (area and depth) and time (sequestration) as described above, in addition to laboratory analysis costs.

In-field measurements

As an alternative approach, in-field measurements were developed as a portable, rapid, precise and cost-efficient alternative to laboratory analysis (dry combustion). While some physical soil sampling is necessary for calibration, the number of laboratory soil sample analyses is drastically reduced. There is, however, a trade-off of lower accuracy than with laboratory methods, though due to lower costs the resolution across a field is much higher (Izaurralde et al. 2013). Soil scanning depth is usually restricted, e.g. to 30 or 50 cm.

Modelling

Soil carbon stocks and changes can also be modelled. Most common SOC models are compartment models which use different mathematical functions to simulate SOC decomposition (Parton et al. 2015). A cost-efficient alternative can be to model SOC in an area using some low-cost or already available data on that area, and interpolating based upon emissions factors and other data from related fields; however, this requires existing data and lacks precision and robustness compared to sampling approaches (Smith et al. 2019).

Technology development

Recent years have seen various companies developing tools for in-field measurements relying on sensor techniques, whose accuracy and cost are still under investigation. These include, for example, spade-like tools with a sensor at the end that is pushed only a few cm into the soil, with measured values transferred directly into soil parameters, including SOC and nutrients, as well as soil physical or structural parameters.[5] Other examples include sensor-based tools fixed to agricultural machinery that detect gamma rays emitted by the soil, which, if appropriately calibrated, may be able to provide information on the SOC content and stocks, though it is unclear whether this is currently being scientifically investigated.

- While in the future satellite and remote sensing data could feasibly support monitoring of soil carbon, current EU Copernicus Sentinel satellite data is not yet sufficient. The resolution of current satellite images is too low (weekly data at 10m scale) to capture most climate-friendly soil management activities, with the potential exception of land-use changes (e.g. agroforestry) and soil coverage over the year. However, any satellite monitoring data would need to be ground-truthed.

3 Examples

Silvoarable agroforestry is a system where woody perennials such as trees or hedges and agricultural crops are grown on the same cropland. Such systems pose significant challenges for SOC determination due to their structural heterogeneity with permanent tree rows within cropland in addition to the natural soil heterogeneity and topography. Permanent tree rows have a higher SOC sequestration rate than cropland and the tree rows also can affect the adjacent crop strips (Golicz et al. 2021). The number of laboratory or in-field measurement samples must be higher to deliver accurate data compared to pure cropland or forest to account for the different components of the system and their interactions.

4 Relevance for the EU

LULUCF[6]: Under the LULUCF regulation and in accordance with UNFCCC methodologies, Member States calculate national level soil carbon (and changes) based upon country-wide measurement programmes, which are then upscaled to the national level using modelling.

The EU Commission sustainable carbon cycles communication[7] states that by 2028 every land manager should have access to verified emission and removal data. It is as yet unclear where this data will be sourced from or verified by; given the challenges identified in this

[5] See https://stenon.io/

[6] Regulation (EU) 2018/841: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG

[7] EU COM (2021) 800 https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf

factsheet, obtaining soil carbon data in particular will be challenging and/or costly and initial soil data to calculate the sequestration rate will be missing.

Voluntary certification mechanisms operating in Europe: Different approaches are used by different existing mechanisms providing voluntary carbon market certificates in Europe to determine soil carbon content, e.g. Label Bas Carbone applies a modelling approach, IndigoAg and Verra Voluntary Carbon Standard allow modelling or measurement approaches, MoorFutures uses a modelling approach (McDonald et al. 2021).

5 Addressing challenges

Determining the carbon content of soil is challenging due to the fundamental difficulties identified in Section 2. Potential measures for dealing with the uncertainties include (McDonald et al. 2021):

- **Quantify/estimate uncertainty:** By identifying uncertainty, it can be communicated or controlled for.
- **Discounting:** Where determination of soil carbon stocks is uncertain, discounts can be applied to any calculations of removals (and resulting offset certificates).
- **Use of conservative assumptions:** This can bias uncertainties in a way that reduces the risk of overestimating removals.

6 Relevant literature

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