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Soil organic matter and soil organic carbon protocol

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Why measure this?

Soil organic matter is a fundamental driver of soil structure, water-holding capacity, and nutrient cycling. Tracking its recovery tells you whether your restoration site is rebuilding the foundation that supports all other soil functions.

Note: To measure soil organic matter you will need access to a soil analysis lab, but many agricultural universities have the capacity to analyze these samples.

What it captures

Represents the recovery of soil carbon stocks (Nelson and Sommers 1996). It is a fundamental control on soil structure. Soils with high soil organic matter have high water-holding capacity and ecosystem productivity. In practice, it is assumed that soil organic carbon comprises a fixed percentage of soil organic matter (58%) allowing for conversion of these metrics. Report soil organic matter (SOM) as % of soil mass. To convert to soil organic carbon (SOC) stocks on a per-volume basis, multiply by bulk density (see the Bulk Density Protocol (01)).

Important caveat: Sampling the top 0-10 cm captures the biologically active surface layer, not the total soil carbon pool. Deeper carbon (below 30 cm) exists but responds slowly to land-use change. This protocol tracks changes in surface carbon – the fraction most responsive to restoration management – and should not be interpreted as a complete inventory of belowground carbon stocks.

Sampling

- Take the first soil samples before implementing the project (before planting or fencing an area) and remeasure every three to five years during the same time of year.
- Collect 5-10 samples per plot. See the General Sampling Protocol (00) for plot layout and replication guidance.
- Do not sample within 48 hours of heavy rainfall. Saturated soils distort bulk density measurements and can bias organic matter estimates.

Materials needed

- Soil corer or soil auger (50-100 mm core diameter)
- Ziploc bags (1 gallon)
- Scale or balance (grams)
- Field notebook
- Masking tape
- Sieve (< 2 mm)
- Permanent marker
- Pen or pencil

Procedure

Confirm lab access (see note above) and turnaround times before beginning fieldwork. If no analytical lab is available, loss on ignition (LOI) can be performed with a muffle furnace and a balance (see Choosing an analysis method).

1. Remove the vegetation and superficial litter layer.
2. Collect soil with a corer at 0–10 cm depth (the recommended default). Sample to 0–20 cm for organic horizon assessment, or to 30 cm only when calculating volumetric SOC stocks. You do not need to reach 30 cm for routine monitoring.
3. Label the Ziploc bags with site name, date, depth, and replicate number.
4. Transfer the soils to Ziploc bags and air dry until constant weight (typically 3–7 days). If air drying is not possible immediately after sampling, store the samples at 4 °C in a fridge. Do not freeze samples.
5. Once the soil samples are dry, sieve them through a < 2 mm sieve to remove rocks and coarse fragments.
6. Place the sieved soil samples into new Ziploc bags (save approximately 50 grams of soil per sample; some methods require less).
7. Deliver the dry and sieved samples to a local soil analysis lab.

Note: Steps 5 and 6 can be skipped if your local lab accepts unsieved samples.



Choosing an analysis method

Loss on ignition (LOI): Simplest and cheapest method. Heat samples at 550 °C for 4-6 hours, or until constant weight. Measures SOM, not SOC directly. Good for tracking relative changes over time at a single site.

Walkley-Black (wet oxidation): Most common wet chemistry method. Measures SOC. May need correction factors for incomplete oxidation. Requires hazardous chemicals (chromic acid).

Dry combustion / elemental analyzer: Gold standard for SOC measurement. An elemental analyzer is an automated lab instrument that measures carbon by dry combustion. Most expensive. Required for carbon credit verification programs.

At early project stages, focus on the particulate organic matter (POM) fraction. POM consists of partially decomposed plant fragments – bits of roots, leaves, and wood – that are visible to the naked eye. It is more sensitive to management changes and land-use disturbance than mineral-associated organic matter (MAOM), making it a better early indicator of recovery (Lehmann et al. 2001). To measure POM, ask your soil analysis lab to run a particle-size fractionation: soil is dispersed in sodium hexametaphosphate solution and passed through a 53 µm sieve. The organic material retained on the sieve is POM. POM responds to management changes within 1–3 years, while MAOM changes over decades.

If resources allow, quantify total soil carbon and nitrogen to track recovery of soil biogeochemical cycles. pH is another inexpensive indicator of soil nutrient availability and pairs well with SOM measurements.

Calculating results

SOM (% of soil mass): Determined by your chosen analysis method (LOI, Walkley-Black, or elemental analyzer). Report as % of dry soil mass.

SOC from SOM: $\text{SOC (\%)} = \text{SOM (\%)} \times 0.58$ (this conversion factor is approximate; it can range from 0.45 to 0.65 depending on soil type and organic matter composition – use a locally calibrated factor when available)

Mineral soil SOC stock: $\text{SOC (kg m}^{-2}\text{)} = \text{Bulk density (kg m}^{-3}\text{)} \times \text{C content (g g}^{-1}\text{)} \times \text{Soil depth (m)}$

Organic layer SOC stock: $\text{SOC (kg m}^{-2}\text{)} = \text{Dry weight of organic layer (kg m}^{-2}\text{)} \times \text{C content (g g}^{-1}\text{)}$

In calcareous soils (pH > 7.5), subtract inorganic carbon from total carbon before calculating SOC stock: $\text{SOC} = \text{Total C} - \text{Inorganic C}$. Use a sizzle test with 1M HCl and a dropper to check for carbonates. If the soil sizzles, carbonates are present and will inflate your carbon values. Either (a) pretreat subsamples with dilute HCl to remove carbonates before analysis, or (b) use an elemental analyzer that can distinguish organic from inorganic carbon. If using LOI, carbonate interference cannot be corrected – switch to wet oxidation or dry combustion for calcareous soils.

Bulk density is required for all stock calculations. See the Bulk Density Protocol (01).

Important considerations

- Bulk density is essential to convert SOM or SOC concentrations to carbon stocks. See the Bulk Density Protocol (01).
- Soil organic matter and soil organic carbon are not evenly distributed over large areas, soil depths, and soil types, or along topography. The calculation of soil organic carbon stock is influenced by soil type.
- When using LOI, apply site-specific or regionally calibrated conversion factors rather than a single universal constant.

References

Anderson, J.M. and Ingram, J.S.I. (1994). Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd ed. CAB International.

Toro, L., et al. (2025). Integrating belowground recovery into tropical forest restoration design and monitoring. BioScience. <https://doi.org/10.1093/biosci/biaf097>

Useful resources

- Talk on quantifying soil carbon change - <https://www.youtube.com/watch?v=vrtru5wzwgQ&t=666s>
- Oldfield, E.E. et al. (2023). Determining the optimal sample size for quantifying SOC stock changes: <https://www.sciencedirect.com/science/article/pii/S0016706123003968>

See also

Sampling Protocol (00), Bulk Density Protocol (01), pH Protocol (04). Bulk density is required for carbon stock calculations, pH correlates with SOM and nutrient availability.

Questions or Feedback?

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