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USDA LTAR Common Experiment measurement: Soil organic carbon stocks and change V.1

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Abstract

The change in soil organic carbon (SOC) over time provides an integrated indicator of carbon (C) balance in agricultural systems and an integral metric of soil health. Determination of SOC concentration and soil bulk density allows calculating the mass of SOC accumulated in soil, and changes in SOC over time reflect the system's C balance. In most soils, measurable SOC changes require a minimum sampling interval of 10 years, depending on local factors such as existing SOC stores and the degree of management change. Thus, we recommend taking whole-profile soil cores at decadal intervals for most soils, with surface soil samples perhaps taken more frequently. Whole-profile samples should extend to the system's maximum rooting depth, usually into the C horizon; in most arable soils, a 1 m depth will be adequate, but some locations will require deeper or shallower sampling. We recommend increment sampling at four depths (0-10, 10-25, 25-50, and 50-100 cm or deeper/shallower as appropriate). However, in some cases, horizon-based sampling may pertain so long as horizons are readily identifiable. In either case, a consistent sampling depth and increments at known locations are crucial for reliably detecting SOC change over decades. Generally, periodic sampling should be timed to the same crop phase in cropped systems and, to minimize year-to-year variability in root and residue inputs, to the same time of year in cropped and grazed systems. Pre-plant or post-harvest sampling in cropped systems avoids tillage and fertilizer artifacts and minimizes plant disturbance and soil bulk density variability. Processing requires soil sieving, drying, and grinding before analysis with a dry combustion CN analyzer; wet combustion and loss-on-ignition methods are unacceptable. For perennial systems, quantify roots as a persistent soil C pool. For soils with detectable carbonate minerals, inorganic C must first be removed by acid fumigation or analyzed independently for later subtraction. Keep archived soil in glass containers in temperature-controlled rooms for later analyses. Calculate SOC stocks using two methods, spatial coordinate and equivalent soil mass (normalized mass per unit area), to facilitate cross-site comparisons. In both cases, express SOC as Mg C ha^{-1}.

Guidelines

General Principles

Soil organic carbon (SOC) is a crucial attribute of soil function. Changes in SOC stocks over time reveal changes in the system C balance because the residual stock of SOC is the balance between C gains and losses. The approach described here is applicable to the plot and field scales with careful attention to timing and sampling locations. Detecting system-level SOC change requires sampling surface and subsurface horizons in a way that collects intact cores with minimal compaction; usually, this task is achievable with a hydraulic coring device that collects soil cores in acrylic sleeves.

Sampling to detect meaningful SOC change is usually performed at decadal intervals or longer because, in most systems, changes in SOC are typically small compared to the standing stock of SOC, and spatial variation contributes significantly to measurement uncertainty. The combined effects mean that usually, more than 10 years pass before statistically significant changes in SOC are detectable using modern technology (Necpálová et al. 2014). Significant changes at depth, where carbon contents are lower and more spatially heterogeneous, may take much longer (Kravchenko and Robertson, 2011). That said, changes over shorter intervals may appear in surface horizons depending on factors such as initial SOC content and management change—for example, converting a field in the Conservation Reserve Program to an annual crop can result in a rapid SOC decrease. Micrometeorological approaches such as eddy-covariance might allow the detection of small changes over shorter intervals by measuring the exchange of carbon dioxide (CO_2) between the plant–soil system and the atmosphere; however, these methods are expensive and do not work at the plot scale.

A 1 m sample depth will be adequate in most arable soils, but some locations will require deeper sampling (to capture total rooting depth) and others shallower (to avoid rock). We recommend depth increment sampling, which has the advantage of simplicity and a greater likelihood of maintaining consistent depth intervals over decades. Sampling intervals should include at least four increments: 0-10 cm, 10-25 cm (or 10-30 cm for deeper A horizons), 25-50 cm (or 30-50 cm), and 50-100 cm (or deeper/shallower as appropriate). However, in some cases, horizon-based sampling may pertain if the horizons are well differentiated and can be detected without ambiguity by different investigators. In either case, consistent sampling depth and increments at known locations are crucial for reliably detecting SOC change over decades.

The time of year of sampling also affects the ability to reliably detect SOC change, especially in surface horizons under the influence of tillage, residue management, grazing, and other seasonal factors affecting C cycling. Thus, sampling over the years should be timed to the same season. In cropped systems, sampling should occur in the same crop phase where possible and when comparing cropped and grazed systems to the same time of year. In cropped systems, pre-plant or post-harvest sampling avoids most management artifacts and minimizes the effects of plant disturbance and seasonal differences in soil bulk density.

Refrigerate sampled soils by cutting cores into depth increments and drying, sieving, weighing, and pulverizing soils before CN analysis and processing. SOC is stable once the soil is dry, so refrigeration is unnecessary after drying. Analyze pulverized soils with a dry combustion CN analyzer. Avoid C analysis by the loss on ignition (LOI) and wet combustion methods such as Walkley–Black, used by many commercial labs, because they do not provide a direct measure of total C and are not sufficiently precise for certainty in SOC stock change determination. In perennial systems, tracking soil C in root pools may also be important—in this case, roots can be removed during sieving and analyzed separately. Some soils

contain detectable carbonate minerals, so inorganic C must first be removed by acid fumigation or analyzed independently for later subtraction. Estimate SOC stocks using two methods, spatial coordinates and equivalent soil mass (normalized mass per unit area), to maximize cross-location comparability. In both cases, express SOC as Mg C ha^{-1}.

Archive processed soils for future research questions and to calibrate temporal changes possibly due to processing, instrumentation, or other technical differences between long-term sampling times. Keep archived soil dry in sealed glass containers in temperature-controlled rooms.

Materials

Soil sampling and archiving:

- Hydraulic soil core sampler with a ≥ 5 cm diameter probe, 1 m or more in length, capable of removing intact cores in sleeves (e.g., Giddings Model MGSRTS [Giddings Machine Company, Windsor CO] or Geoprobe Model 540MT [Geoprobe Systems, Salina KS])
- Soil push probe 2-3 cm in diameter, 30 cm in length (e.g., Oakfield Model LS (Oakfield Apparatus, Fond du Lac Wisconsin) or JMC Model PN031 (JMC Soil Samplers, Newton IA) or equivalent
- 7 mL plastic or glass vials
- Paper and plastic bags
- Plastic liners with caps adequate for the selected hydraulic soil corer
- Hermetically sealable glass containers (e.g., canning jars)
- Labels
- 50-50 bentonite + sand mix to fill deep holes

Lab materials for soil organic C concentration analysis:

- Soil pulverizer (e.g., SPEX Shatterbox 8530 [Spex SamplePrep, Metuchen NJ], roller mill, or mortar and pestle
- CN dry combustion analyzer (manufacturers include Costech (Valencia CA); Leco (St. Joseph, MI), and Elementar (Ronkonkoma, NY))
- Sample containers for the dry combustion analyzer (e.g., Elemental Microanalysis D1042 8 × 5 mm tin capsules (Elemental Microanalysis, Marlton NJ)) or as specified by the analyzer manufacturer (e.g., ceramic boats and metal cuvettes might be appropriate for some analyzers)
- For acid pre-treatment, use sample containers as specified by the analyzer manufacturer (e.g., silver rather than tin capsules if otherwise using tin capsules)
- Forceps for moving capsules or other analysis containers to a microbalance or desiccator
- Micro spatula, scoop-shaped
- Sample tray appropriate for storing weighed samples in desiccators before analysis (e.g., a 96-well plate if using tin capsules)
- Electronic microbalance (resolution to 0.001 mg)
- Desiccator to store weighed samples before analysis
- Analytical standards (acetanilide, atropine, or phenacetin)
- Check standard (purchased or stored soil standard, e.g., Low Organic Content Soil, Elemental Microanalysis, Marlton, NJ; 1.55 %C, 0.13 %N, or other soil with C and N concentrations similar to the analyzed soils)

For carbonate pre-tests:

Option 1

- pH meter

Option 2

- Small weigh boats or beakers,
- eye dropper or syringe
- 1 N HCl acid (~10 mL)

For acid pre-treatment, if needed to remove carbonates:

- Microliter pipette
- Deionized water
- Desiccator (5 L)
- 12 M HCl (100 mL)

Sample Collection

1 Define the objectives of your sampling. Are you conducting long-term monitoring or not? Decadal whole-profile soil sampling involves collecting samples from a predetermined set of sites regularly over the years. Surface sampling may have additional or different sampling sites. Select sites that are representative of the area or ecosystem you are studying. Consider factors such as soil types, land use, vegetation, and historical data. Below are more details suggested to follow for each sampling strategy.

1.1 **Decadal whole-profile soil sampling**

Whole-profile soil samples should be taken as intact cores in acrylic sleeves of at least 5 cm diameter to the recommended depth, using a hydraulic probe to avoid compaction. Do not take samples when soils are too wet to avoid compaction of cores and research plots or too dry, when soil strength may impede probing, or when increments may be difficult to keep intact during processing.

Generally, sample soils into the C horizon; a 1 m depth will often be adequate in arable soils, but some situations may justify deeper sampling. In many rangelands and forests, soils are much shallower. We recommend minimum sample depth increments of 0-10 cm, 10-25 cm (or 10-30 cm for deeper A horizons), 25-50 cm (or 30-50 cm), and 50-100 cm (with maximum depths deeper or shallower as appropriate). For no-till fields or situations where soil erosion is evident, consider sampling at the 0-5 cm (and 5-10 cm) depths, where soil organic C stock differences may often be most apparent. Consistent sampling depth and measurement increments at known locations are crucial for reliably detecting small changes over decades. Choose the best approach for your site and maintain depth consistency throughout the SOC stocks monitoring period.

Decadal sampling intervals will depend on the experimental design and rotation lengths of the treatments compared. Take samples post-harvest on the same (or similar) rotation phase at each interval.

Example 1: Two- and five-year rotations: sample every 10 years (bolded below) on the same crop phase.

	A	B	C	D
	Year	Two-Year Rotation	Five-Year Rotation	Sampling Year
	0	Corn	Corn	X
	1	Soybean	Soybean	
	2	Corn	Wheat	

	A	B	C	D
	3	Soybean	Alfalfa	
	4	Corn	Alfalfa	
	5	Soybean	Corn	
	6	Corn	Soybean	
	7	Soybean	Wheat	
	8	Corn	Alfalfa	
	9	Soybean	Alfalfa	
	10	Corn	Corn	X

Example 2: Three-, four- and six-year rotations: sample every 12 years on the same crop phase.

	A	B	C	D	E
	Year	Three-Year Rotation	Four-Year Rotation	Six-Year Rotation	Sampling Year
	0	Corn	Corn	Corn	X
	1	Soybean	Soybean	Soybean	
	2	Wheat	Wheat	Wheat	
	3	Corn	Alfalfa	Alfalfa	
	4	Soybean	Corn	Alfalfa	
	5	Wheat	Soybean	Alfalfa	
	6	Corn	Wheat	Corn	
	7	Soybean	Alfalfa	Soybean	
	8	Wheat	Corn	Wheat	
	9	Corn	Soybean	Alfalfa	
	10	Soybean	Wheat	Alfalfa	
	11	Wheat	Alfalfa	Alfalfa	
	12	Corn	Corn	Corn	X

For plot-scale experiments, take cores in at least three locations per plot. For field-scale experiments, take a sufficient number of cores to represent topographic variation—consider nesting by topographic position (e.g., top slope, mid-slope, and toe slope). In both cases, GPS-mark the sample locations to facilitate sampling nearby in subsequent years to detect long-term changes better. Refill holes with a 50-50 mix of bentonite and sand or pure sand to avoid resampling that exact location later. Transport and store the soil cores in their plastic liners (do not composite by depth increment before weighing increments) and keep them at 4 °C until processing. If same-day processing, store soils in shaded containers.

1.2 **Surface soil sampling**

For non-decadal sampling intervals, align with the crop phase. Take surface soils as above but without needing intact cores/plastic sleeves and in most cases without needing a hydraulic sampler. Take samples to the same surface soil depth interval used for deep cores (0-25 or 0-30 cm) using a push core of 2-3 cm diameter. Take a sufficient number of cores at each sampling location to represent local variability due to plant spacing; in row crops, for example, take samples at different distances between the middle of a row and the midpoint between rows—be careful not to oversample one plot location at the expense of another. Composite samples in plastic bags in the field. Store at 4 °C until processing. If same-day processing, store soils in shaded containers.

Soil Processing

2 This step is very important and it is recommended to maintain meticulous records throughout the processing steps. Document any deviation from the standard soil processing procedure suggested below.

2.1 Label paper bags to be used for drying soils with sample information (e.g., date, experiment, plot, station, core number, and depth increment). Consider including barcodes in your labels if you have an automated system at your site.

2.2 Lay the core horizontally on a long cutting board. If recording horizon depths (optional), do so now. If condensation on the inside of sleeves obscures viewing, cut sleeves longitudinally to create an unobscured view of the soil. Note cores with obvious compaction and consider excluding them. Alternatively, engage with your NRCS state soil scientist or other specialist to conduct a thorough soil profile description, including horizon analysis at your site, and measure the Ap horizon for comprehensive assessment every ten years.

2.3 Lift the core slightly to remove the end caps. Push the core out of the liner from the deep end using a dowel of the approximate diameter of the liner or a similar tool. If pushing out the core is impossible without compaction, carefully cut open the core liner using shears or a utility knife.

2.4 Cut each soil core into the multiple-depth increments noted in Section 1.1 using a sharp knife or cutting tool. Soil cores from the same plots or topographic positions may be composited by depth increment to achieve the desired soil sample mass while considering factors that may affect the physical integrity of the sampled treatment over time.

2.5 Record the fresh weight of each soil depth increment (FWsoil). If it differs from the expected value, record the actual depth of each soil depth layer.

2.6 Pass each soil depth increment through a 2 mm sieve to remove gravel and identifiable plant material > 1 cm. In perennial systems, keep and after drying record the weights of plant roots > 1 cm long to include root C stocks in SOC stores.

2.7 Record the weight or volume of the gravel (FWgravel or Vgravel) and discard it unless it contains mineral-associated organic C, such as ironstone concretions. Assess gravel volume by assuming a standard density (2.1 g cm^{-3}) or displacement (the mL of water displaced upon placing gravel in a water-filled graduated cylinder).

2.8 Mix the sieved soil well, then place 50 g in a small paper bag or soil tin for drying at 105 °C to calculate the water content (DWsoil). Dry for 24 h or until mass loss ceases. Soil dried at 105 °C cannot be used for C and N analysis because high heat can volatilize N and C.

2.9 Place the remaining soil in a paper bag and dry at 60 °C for 48 h or air-dry for several days until no further mass loss, in either case. It is not necessary to weigh this mass.

2.10 Place 500 to 1000 g of dried, well-mixed soil into a glass jar for archiving.

2.11 Remove a 50 g subsample from the jar for pulverizing to less than 250 microns in a shatterbox or equivalent mill or mortar and pestle. Store the pulverized sample in a labeled 7 mL vial for later C and N analysis.

Soil Archiving

3 Soil organic carbon remains very stable in properly archived samples. Store archived samples in the same room or storage facility in properly labeled boxes or plastic totes with labels indicating the PI's last name, Year, Field or Experiment, Treatment, Replicate or Plot number, and Depth increment. Barcodes may be useful. Placing a second label inside the soil container may also be useful. Update the archive database after each sampling campaign. Archived samples are crucial for calibrating C analyses between decadal sampling events to control for unanticipated changes in instrumentation, processing workflows, and standards.

Testing for and Removing Inorganic Carbon

4 Soil depth increments in which the pH is greater than 7.2 (test pH in a 1:1 soil:deionized water mixture after allowing for an hour or more equilibration time at room atmosphere) may require quantification or removal of inorganic C. Detect the presence of significant inorganic C as follows:

4.1 Place ~0.5 g of pulverized soil into a weighing boat or beaker.

4.2 Add five drops of 1 N hydrochloric acid (HCl).

4.3 If no bubbling is detected, stir gently to confirm (compare to soil with no carbonates to ensure bubbling is from carbonate dissolution and not from the physical release of entrapped bubbles).

4.4 Record the presence or absence of carbonates and discard the sample.

4.5 If effervescence is detected, inorganic C must be removed by acid fumigation before total C analysis or measured for subtraction from total C concentrations. To quantitatively measure inorganic C, refer to the methodology outlined in NRCS Technical Note 450-03 (2019) or Sherrod et al. (2002).

5 **To remove inorganic C (Harris et al., 2001):**

5.1 Transfer an aliquot of finely pulverized soil to the silver capsule or other container used for CN analysis and place it unsealed in a desiccator. This aliquot is equivalent to that used for CN analysis (see below). Always clean forceps, spatulas, and the microbalance area before and in between weighing samples with lab wipes and 70% ethanol. Do not touch the analysis container—fingers are C and N contamination sources.

5.2 Add 90 µL of deionized water to each open capsule to wet the soil.

5.3 Place a beaker with 100 mL of concentrated (12 M) HCl into the desiccator. Close the desiccator and allow at least 6-8 h for carbonate dissolution but not more than 24 h because extended exposure can embrittle capsules.

5.4 Remove samples from the desiccator and place them in a 60 °C oven until dry (4-24 h).

5.5 If using silver capsules, a tin capsule may be needed to enclose a silver capsule embrittled by acid fumigation to avoid potential sample loss when sealed. Discard the sample if loss occurs.

5.6 Note that fumigated soils will negatively impact analyzer combustion tubes and seals. In particular, combustion and reduction reagents will need replacing approximately twice as often. Only ~80 fumigated samples can be run per quartz inset, as they have more residue than non-fumigated samples. When replacing the quartz insert, thoroughly check the elemental analyzer for evidence of corrosion near contact points and around seals. Bake out the analyzer every three months at 110°C for 6 h (as opposed to every six months under normal operating conditions) during acid fumigation runs.

Analyzing for Total Organic Carbon

6 In the absence of inorganic C, SOC is equal to total C. Determine total C using dry combustion gas chromatography (NRCS Technical Note 450-03, 2019; Nelson and Sommers, 1996) on an elemental analyzer calibrated with an analytical standard (acetanilide (C_8H_9NO) or atropine ($C_{17}H_{23}NO_3$)), with three analytical reps per sample. Run a check standard (e.g., Low Organic Content Soil, Elemental Microanalysis, Marlton, NJ; 1.55 %C, 0.13 %N, or another soil with C and N concentrations similar to the analyzed soils) every 12 samples per plate of 72 samples.

6.1 Always clean forceps, spatulas, and the microbalance area before and in between weighing samples with lab wipes and 70% ethanol. Do not touch the analysis container—fingers are C and N contamination sources.

6.2 Using the microbalance, tare the sample container (e.g., a tin or silver capsule or a ceramic crucible) and place an appropriate amount of sample into the cup. The amount of soil to be weighed depends on the instrument and the C content of the sample—follow manufacturer recommendations to test for proper amounts; note that low C soils from deeper horizons may require a greater analysis mass than surface soils. Record the weight.

6.3 Prepare a blank and four standard containers using the same procedure, but instead of soil, use four different weights of the standard acetanilide or atropine sufficient to bind the concentrations expected based on prior testing. Follow with one soil check standard, prepared as above.

6.4 Continue to fill the sample tray with three analytical replicates for each sample. Include a soil check standard after approximately every 12 sample cups. Store the sample tray in a desiccator until analyzed.

6.5 Follow the instrument manufacturer's instructions for C analysis.

6.6 Rerun samples if the coefficient of variation (CV) for the three analytical replicates exceeds 10% or if check standards are not within 10% of expected values.

Intermediate Calculations

7 **Soil gravimetric water content per soil depth increment**

7.1 Determine gravel-free fresh weight (FW; g): Eq. (1)

$$FW = FWtotal - FWgravel$$

where

FWtotal = fresh weight of soil + gravel of a soil depth increment [g]
FWgravel = fresh weight of gravel found in the soil depth increment measured [g]

7.2 Determine soil water content by only oven-drying a subsample of the previously measured FW (SWCsub; g H_2O per g dry soil):

$$SWCsub = (FWsub - DWsub)/FWsub$$
Eq. (2)

where

FWsub = fresh weight of a subsample of a gravel-free soil depth increment [g]
DWsub = dry weight (105 °C) of a soil depth increment subsample [g]

7.3 Determination of the dry weight of the entire soil depth increment (DWsoil; g dry soil) [g]:

$$DWsoil = FW/(1 + SWCsub)$$
Eq. (3)

Terms are included above.

8 Determination of soil bulk density

If soil compaction is not detectable during soil core sampling, determine gravel-free bulk density from the dry weight of soil within the core volume of each soil depth increment. For soils with a substantial gravel content, gravel weights or volumes are used to adjust bulk density values by first subtracting gravel mass from total soil mass. Alternative methods for the bulk density determination are described in Elliott et al. (1999) or Grossman and Reinsch (2002).

8.1 Determine total bulk density (BDtotal; g cm^{-3} or Mg m^{-3}) per soil depth increment:

$$BD = (DWsoil + FWgravel)/V$$
Eq. (4)

where

V = volume of the core soil depth increment in cm^3 (cylindrical volume = π * r^2 * h, where r = inside radius of the soil core sleeve or probe (cm) and h = depth increment (cm))

Other terms are as above.

8.2 Determine gravel-free bulk density (BDgravel-free; g cm^{-3}) per soil depth increment:

$$BDgravel\text{-}free = DWsoil/V$$

Eq. (5)

Terms are included above.

9 **Determination of soil carbon concentration**

CN analyzers usually report C as the percentage of C in a dried sample (g C per 100 g dried soil). Report the average values from analytical replicates.

Estimating SOC stocks, change, and rate of change

10 Report Soil C stocks as Mg C ha^{-1} for each soil depth increment using average gravel-free bulk densities by soil depth increment. Total profile C is the sum of each soil depth increment.

10.1 **Spatial coordinate method (Gifford & Roderick 2003)**

1) Calculate SOC stocks by increment (SOCstock; Mg SOC ha^{-1}) by multiplying SOC concentration by the averaged gravel-free bulk density of each soil depth increment:

$SOC_{stocks.increment}$ = (DL) * (BDgravel-free) * (SOC) * 0.1

Eq. (6)

where

DL = soil depth increment [cm]

BDgravel-free = gravel-free bulk density of a soil depth increment [g cm^{-3}]

SOC = SOC concentration [mg SOC g $soil^{-1}$]

2) Change in SOC stocks ($\Delta SOC_{stocks.increment}$; Mg SOC ha^{-1}) by soil depth increment measured at two sampling times:

$\Delta SOC_{stocks.increment} = (SOC_{stocks.increment})_{time2} - (SOC_{stocks.increment})_{time1}$

Eq. (7)

3) Cumulative profile SOC stocks ($SOC_{profile.stocks}$; Mg SOC ha^{-1}) if SOC stocks were determined at multiple depths:

Eq. (8)

$SOC_{profile.stocks} = SOC_{stocks.increment1} + SOC_{stocks.increment2} + \ldots + (SOC_{stocks.incement})_n$

Terms included above.

Calculate rates of change by dividing the difference in SOC stocks by the number of years between sampling intervals (Mg SOC ha^{-1} $year^{-1}$).

10.2 Equivalent soil mass method (Wendt and Hauser, 2013)

The concept of equivalent soil mass (ESM) evaluates SOC stocks based on a standard amount of soil mass per unit area. This approach addresses variations in soil mass through time due to factors such as soil management or erosion. Soil profiles can be visualized as soil mass layers rather than soil depth layers (Figure 1).

For instance, the soil mass weights from different profile layers are somewhat similar to their depths, 0–1000 Mg ha^{-1} (0-10 cm), 1000–2000 Mg ha^{-1} (10-20 cm), and 2000–3000 Mg ha^{-1} (20-30 cm), and will vary in a given depth because of changes in bulk density. However, the soil mass weight of a soil layer is less variable, allowing more sensitive calculations or more consistent comparisons of SOC changes.

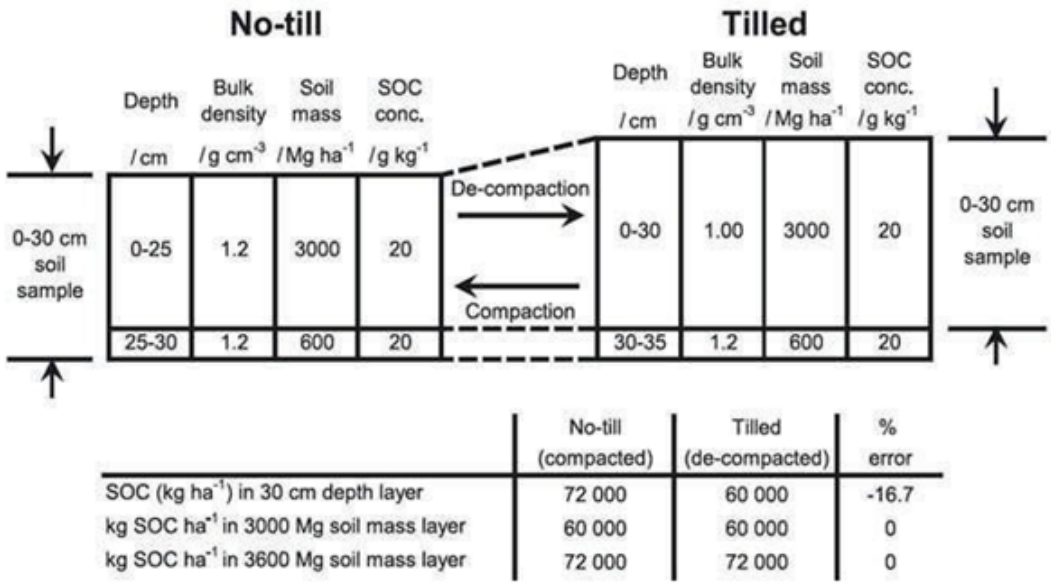

Figure 1. Visualization of the bias induced by quantifying soil OC stocks at fixed depths when there are differences in bulk density. Source: Wendt and Hauser, 2013; used with permission.

1) Calculate the soil mass weight (SWt; Mg $ha^{-1)}$ of each soil depth increment:

$$SWt = (DWsoil/Area) = [DWsoil/(\pi * (D/2)^2] * 10,000$$
Eq. (9)

where

DWsoil = oven-dry soil weight of each soil depth increment [g dry soil]
Area = area sampled by the probe or auger [cm^2],
D = diameter of the cross-sectional area of the soil core [mm]

If multiple soil cores are combined to form one sample, the area sampled is ($\pi \times (D/2)^2 \times N$), where N is the number of core samples.

2) Calculate the cumulative SOC stocks ($SOC_{profile.stocks}$; Mg SOC ha^{-1})

Eq. (10)

$$SOC_{profile.stocks} = (SWt * SOC * 10^{-3})_{increment1} + (SWt * SOC * 10^{-3})_{increment2} + \ldots + (SWt * SOC * 10^{-3})_{increment.n}$$

Terms are included above.

The cumulative soil and SOC masses are calculated by summing their respective soil depth increment masses, calculated in Equations (9) and (10) to any given depth; for example, if cores were split into two equal-depth increments, the cumulative soil and SOC masses to 30 cm are the sum of their respective masses in the 0–15 and 15–30-cm soil depth increments; if cores were split into three equal-depth increments, the cumulative masses to 45 cm are the sum of their respective masses in the 0–15, 15–30, and 30–45-cm soil depth increments.

A fitted curve, in this case a cubic spline, provides good estimates of cumulative SOC contents for any chosen reference soil mass in the profile. The cubic spline function fits a smooth curve to a series of points with a piecewise series of cubic polynomial curves.

See Wendt and Hauser (2013) for detailed examples.

Recommendations for data collection

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Table 1. Summary of recommendations for measuring soil organic C stock as an indicator of system C balance.

	A	B	C	D
	Attribute	Preferred	Minimum	Comments

	A	B	C	D
	Spatial scale	Plot and field	Plot	The field-scale protocol could be validated by eddy covariance or another available tower-based micro-met method.
	Frequency	5-10 years	Five years for surface samples and 10 years for deep core samples	A 5- to 10-year sampling interval is sufficient for determining C balance. If other objectives need more frequent sampling, including SOC stock determined with those measures could increase the sensitivity of C stock determinations.
	Covariate metrics	Soil pH Soil profile description	None Every 10 years	These samples could also be used to assess soil fertility. Engage with a state soil scientist or other specialist to conduct a thorough soil profile description, including horizon analysis, and in particular, measure the A/Ap horizon.

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