Chapter 3
Measuring Change in Soil Organic Carbon Storage

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3.1 INTRODUCTION

Organic carbon (C) must be among the most commonly analyzed soil constituents, starting with the earliest soil investigations. Already in the nineteenth century, chemists were routinely analyzing soil C (e.g., Lawes and Gilbert 1885). Initially, these analyses were done to investigate pedogenesis and to assess soil productivity, both of which are closely linked to organic C (Gregorich et al. 1997). But more recently, scientists have been analyzing soil organic C (SOC) for another reason: to measure the net exchange of C between soil and atmosphere (Janzen 2005). Indeed, building reserves of SOC has been proposed as a way of slowing the rising atmospheric CO_2 concentrations caused by burning fossil fuel (Lal 2004a,b).

Measuring SOC to quantify soil C ''sinks'' requires more stringent sampling and analyses than measuring SOC to evaluate productivity. Where once it was sufficient to measure relative differences in concentration over time or among treatments, now we need to know the change in amount of C stored in Mg C per ha. Reviews of SOC measurement typically focus on the chemical methods of determining the SOC concentrations after samples have been brought to the laboratory. Here we emphasize soil sampling procedures and calculation approaches to estimate temporal changes in SOC stocks. Uncertainties along the entire chain of procedures, from designing the soil sampling plan, to sampling in the field, to processing and storing the samples, through to chemical analysis and calculating soil C stocks need to be considered (Theocharopoulos et al. 2004).

SOC is dynamic: newly photosynthesized C is added regularly in the form of plant litter, and existing SOC is gradually decomposed back to CO_2 by soil biota. Management or environmental conditions that change the relative rates of inputs and decomposition will effect a change in the amount of SOC stored. Rates of change in SOC (typically less than 0.5 Mg C ha^{-1} $year^{-1}$) are quite small, however, compared to the large amounts of SOC often present (as high as 100 Mg C ha^{-1}, or more, in the top 30 to 60 cm soil layer). Thus changes in SOC can only be reliably measured over a period of years or even decades (Post et al. 2001). Since the distribution of SOC in space is inherently variable, temporal changes (e.g., attributable to management practices, environmental shifts, successional change) must be distinguished from spatial ones (e.g., attributable to landform, long-term geomorphic processes, nonuniform management).

Temporal changes in SOC can be defined in two ways (Figure 3.1): as an absolute change in stored C (SOC at $t = x$ minus SOC at $t = 0$), or as a net change in storage among treatments (SOC in treatment A minus SOC in treatment B, after x years). The former provides an estimate of the actual C exchange between soil and atmosphere; the latter provides an estimate of the C exchange between soil and atmosphere, attributable to treatment A, relative to a control (treatment B). Both expressions of temporal change may be available from manipulative experiments with appropriate samples collected at establishment (assesses spatial variability) and at various intervals (say 5 to 10 years) thereafter.

This chapter provides selected methods for measuring the change in C storage, either absolute or net, typically for periods of 5 years or more. To be effective, the method needs to: measure *organic* (not total) C, provide estimates of C stock change (expressed in units of C mass per unit area of land to a specified soil depth and mass), be representative of the land area or management treatment under investigation, and provide an indication of confidence in the measurements. These methods are applicable, with minor modification, to a range of scales and settings, including benchmarks sites and replicated research experiments.

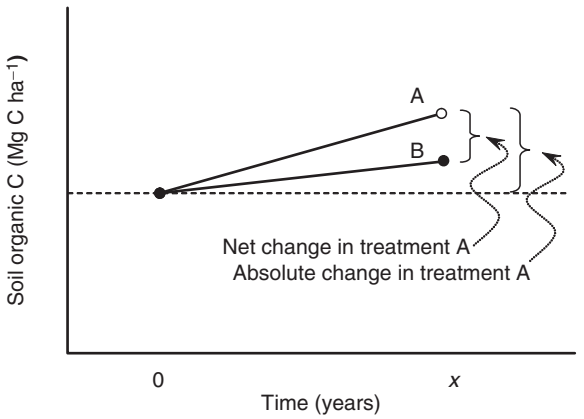

FIGURE 3.1. Illustration of hypothetical changes in soil organic C in two treatments, A and B. For treatment A, the absolute change is the difference in SOC at time = x, compared to that at time = 0. The net change is the difference between SOC in treatment A and that in treatment B, at time = x, assuming that SOC was the same in both treatments at time = 0. The latter approach is often used to measure the effect on SOC of a proposed treatment (e.g., no-till) compared to a standard ''control'' (e.g., conventional tillage).

3.2 SELECTING THE SAMPLING LOCATIONS AND PATTERN

Determining the optimum number and spatial arrangement of sampling points to estimate SOC storage remains as much an art as a science. Nevertheless, careful study of the site, along with clearly articulated objectives can improve the cost-effectiveness and precision of the estimates (VandenBygaart 2006).

3.2.1 Materials

1 Descriptions of soil properties, landscape characteristics, and agronomic history at the study site, from sources such as: soil maps and reports, aerial photos, scientific publications, cropping records, and yield maps.

3.2.2 Procedure

Two general approaches can be used in sampling a study area (e.g., a plot, field, watershed):

a Nonstratified sampling, where the entire study area is considered to be one unit, and sampled in a systematic or random manner.

b Stratified sampling, where the study area is first subdivided into relatively homogeneous units, based on factors such as topography (e.g., slope position), and each unit is sampled separately.

3.2.3 Nonstratified Sampling

1 Obtain an estimate of the likely sample variance and required accuracy for SOC at the study site, based on previously compiled information.

2 Using as much information as available, calculate the number of samples required using Equation 3.1. The required number of samples will increase as variability and the required accuracy increase (Figure 3.2) (Garten and Wullschleger 1999; Wilding et al. 2001). Required accuracy is expressed as in the same units used for the sample mean, and often is less than 10% of that value because even small changes in the mean imply appreciable pedosphere–atmosphere C exchange over large tracts of land.

3 Select an appropriate grid or linear sampling pattern, suited to the study site and sampling equipment.

3.2.4 Stratified Sampling

1 Subdivide the study site into areas likely to have similar SOC stocks, based on factors such as topography or management history.

2 Select the number of sampling sites within each subarea, using Equation 3.1, or Figure 3.2 as a guide, or by fixed allotment. In the latter case, for example, one or several sampling sites may be designated for each of three slope positions within a large research plot.

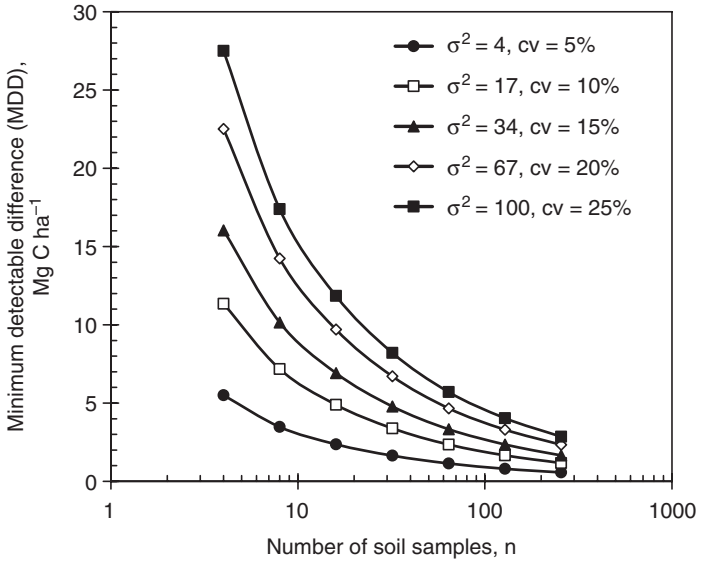

FIGURE 3.2. Decrease in the minimum detectable difference (MDD) between mean soil C at two sampling times for contrasting levels of variance as the number of samples collected at each time doubles (4, 8, 16, ...). The MDD was calculated for $\alpha = 0.05$ significance and $(1-\beta) = 0.90$ statistical power (i.e. probability of rejecting the null hypothesis when it really is false and should be rejected). The lines correspond to increasing variance (σ^2) selected for a hypothetical soil layer containing a mean of 40 Mg C ha^{-1} with the coefficient of variation (cv) increasing from 5% to 25%. (Adapted from Garten, C.T. and Wullschleger, S.D., *J. Environ. Qual.*, 28, 1359, 1999. With permission.)

3.2.5 Calculations

$$n_{\text{req}} = \frac{t^2 s^2}{(d \times \text{mean})^2} \tag{3.1}$$

where n_{req} is the required number of samples, t is the Student's t-value, at the desired confidence level (typically $1-\alpha = 0.90$ or 0.95), s^2 is the sample variance, d is the required accuracy or maximum acceptable deviation from the mean (e.g. $d = 0.10$), and mean is the arithmetic sample mean.

3.2.6 Comments

Sampling patterns and intensities will vary widely, depending on site characteristics and on other factors, notably economic considerations. Often, the number of samples required to achieve the desired sensitivity is exceedingly expensive, and the number of sampling points is somewhat arbitrarily reduced. As well, sampling intensity may have to be reduced in small plots, such as long-term experiments, where excessive soil removal may disturb the site to the extent that future research is jeopardized. But such compromises, if carried too far, may reduce the chance of measuring any differences with reasonable reliability. Studies with insufficient sampling points typically lack statistical power to assess treatment effects. Consequently, the ''cost'' of erroneous conclusions drawn from such data (when the data really are inconclusive) may greatly exceed the ''savings'' provided by reduced sample numbers.

Precisely measuring temporal changes in SOC first depends on identifying or minimizing spatial changes. Spatial changes can be minimized by pairing sampling locations in space (Ellert et al. 2001, 2002; VandenBygaart 2006). This approach allows for effective measurement of SOC changes in time at comparatively few sampling points, but measured C stock change values at these points are not necessarily representative of the entire study site. Conant and Paustian (2002) and Conant et al. (2003) have evaluated similar sampling strategies.

3.3 EXTRACTING AND PROCESSING SOIL CORES

The following procedure is intended for the extraction of soil cores, from agricultural plots or landscapes, for subsequent organic C analysis. It is provided as an illustration, recognizing that individual studies may require modification to satisfy specific objectives and local conditions.

3.3.1 MATERIALS

1 Truck-mounted hydraulic soil coring device.

2 Soil coring tube, with slots 1 cm wide by 30 cm long, and a cutting bit with inside diameter of about 7 cm. The bit usually has slightly smaller diameter (by 1 to 4 mm) than the tube; this difference should be small enough to avoid soil mixing, but large enough to prevent sticking. In dry, coarse-textured soils with weak consolidation this difference should be reduced so there is enough friction to hold the core when the tube is pulled from the soil. The diameter of the coring bit should be measured accurately and recorded for future calculations of soil core density.

3 Piston to push the soil core out of tube. A simple piston can be constructed by attaching a rubber stopper to the end of a wooden dowel.

4 Knife, steel ruler, scissors, wire brush.

5 Aluminum foil trays ($\sim 24 \times 30 \times 6$ cm, used in steam tables for serving food), coolers for transporting trays from field, and heavy polyethylene bags ($\sim 30 \times 50$ cm) to contain trays of field-moist soil.

6 Analytical balance (3000 g capacity, resolution to 0.01*g*), moisture tins (8 cm diameter $\times$ 6 cm tall), drying oven (105°C).

7 Paper ''coffee'' bags with plastic lining and attached wire ties (e.g., Zenith Specialty Bag Co., 11 $\times$ 6 cm base $\times$23 cm height).

8 ''Rukuhia'' perforated drum grinder, with 2 mm perforations (Waters and Sweetman 1955); or another coarse soil grinder and a 2 mm soil sieve.

9 Equipment to measure soil sampling locations. This may be a simple surveyor's tape to measure locations relative to permanent marker stakes in long-term field experiments, or a Global Positioning System (GPS) receiver. For precise pairing (in space) of samples collected at sequential time intervals of several years, a two-stage measuring approach may be useful: the general location is measured relative to permanent reference points or is recorded using a simple GPS receiver,

and the position of the initial cores is marked by burying an electromagnetic marker originally developed to identify underground utilities (Whitlam 1998). Alternatively, high-resolution GPS is available in many regions.

3.3.2 Procedure

1 Before sampling, label paper bags with name, sampling date, location, and soil depth. These bags, eventually to be used for storing the air-dried soils, also serve as labels throughout the sampling process. Weigh the aluminum trays, one for each sample, and record the weight on the tray.

2 In the field, for each sampling point, lightly brush away surface residue and extract a core to a depth of at least 60 cm. Move the core from the vertical to a horizontal position (e.g., in a sectioning trough made of 10 to 15 cm diameter pipe cut lengthwise), and measure the depths of any visible discontinuities (e.g., depth of A_p horizon). Be prepared to discard cores that are unrepresentative (e.g., excessively compacted during sampling, evidence of atypical rodent activity, gouged by a stone pushed along the length of the core during sampling). It may prove useful to push the core (from the deepest end) out in increments, using the top end of the tube as a guide to make perpendicular cuts. Cut the core into carefully measured segments (for example: 0 to 10, 10 to 20, 20 to 30, 30 to 45, and 45 to 60 cm), and place segments into aluminum trays, avoiding any loss of soil. Repeat the procedure for a second core, about 20 cm apart, and composite with the first core segments. Place aluminum trays inside a polyethylene bag, along with the labeled paper bag, fold over polyethylene bag, and store in cooler before subsequent processing indoors.

3 In the laboratory, remove aluminum trays from the polyethylene bags and air-dry at room temperature. Except for very sandy soils, it will be much easier to grind the soils if the field-moist soil cores are broken apart by hand before air drying and subsequent grinding. Great care is required to avoid sample losses during processing and contamination by dust, plant material, paper, or other C-rich contaminants during drying. Wear rubber gloves when handling soil to avoid contamination.

4 Once samples are air-dry, record weight of sample + aluminum tray. Remove a small, representative subsample (e.g., 50 to 80 g, excluding stones and large pieces of plant residue), and determine air-dry moisture content by oven-drying for 48 h at 105°C. Alternatively, the weights of field-moist cores plus trays may be recorded immediately after removal from the polyethylene bag and before they are broken apart and air-dried. In this case, accurate field moisture contents are crucial to estimate the densities of core segments, but spillage when cores are broken apart and mixed may be less consequential than the case when cores are dried before weighing. Thoroughly mix soils before subsampling to determine field moisture content and possibly to retain a field-moist subsample for biological analyses.

5 Crush or grind entire samples to pass a 2 mm sieve, and screen out gravel >2 mm in diameter. All organic material in the sample should be included; if necessary, separately grind roots and other large organic debris to <2 mm, and mix into the sample. A ''Rukuhia'' perforated drum grinder (Waters and Sweetman 1955)

allows efficient, effective grinding of soil samples for SOC analysis. For each sample, remove and record the air-dry weight of gravel >2 mm in diameter.

6 Place coarsely ground samples in labeled ''coffee'' bags for storage under cool, dry conditions, before analysis. For permanent storage (longer than 1 year), soil samples should be placed in sealed glass or plastic jars, and kept under cool, dry, and dark conditions. If finely ground soil is required (e.g., for elemental micro-analysis), the coarsely ground (<2 mm) soil should be thoroughly mixed and subsampled before bagging.

3.3.3 Calculations

1 Air-dry moisture content

$$W_s = (M_{AD} - M_{OD})/(M_{OD} - M_{tin}) \tag{3.2}$$

where W_s is the water content of air-dry soil, by weight (g g^{-1}), M_{AD} is the mass of air-dry soil and tin (g), M_{OD} is the mass of oven-dry soil and tin (g), and M_{tin} is the mass of tin (g).

2 Density of core segment

The following calculation provides an estimate of the density of the soil core segments. This may not be identical to more exacting estimates of soil bulk density, because compaction or loose surface layers may thwart efforts to collect samples of a uniform volume without altering the original mass *in situ*. Despite this, core segment density is preferred over a separate bulk density measurement for calculating SOC stocks.

$$D_{cs} = [(M_{cs} - M_g)/(1 + W_s)]/[L_{cs}\pi R_b^2] \tag{3.3}$$

where D_{cs} is the density of core segment (g cm^{-3}), stone-free mass averaged over the entire sample volume, M_{cs} is the total mass of air-dry soil in the core segment, M_g is the mass of gravel (g), L_{cs} is the length of core segment (cm), and R_b is the core radius (cm), i.e., inside diameter of coring bit/2. If the sample is a composite of more than 1 core segment, then L_{cs} is the cumulative length. For example, if the sample contains two segments from 10 to 20 cm depth, then $L_{cs} = 20$ cm.

3.3.4 Comments

The procedure described above may be modified to make it applicable to individual study sites and objectives. Some of the important considerations include:

a *Sampling depth*

The sampling depth should, at minimum, span the soil layers significantly affected by the management practices considered. For example, it should include the entire depth of soil affected by tillage. The preferred depth may also vary with crop type; for example, studies including perennial forages may require deeper samples than those with only shallow-rooted annual crops. As the number of sampling depths increases, so does the effort and cost of sampling, processing and analysis. Detection of a given

change in soil C (e.g., 2 Mg C ha^{-1}) becomes more difficult as the change is averaged over increasingly thick soil layers containing increasing soil C. In such instances, it may be reasonable to calculate changes for a layer thinner (to a minimum of perhaps 30 cm) than that sampled, although it might have been preferable to shift resources from sampling deeper layers to sampling at more points. The best compromise may be to sample to below the zone of short-term agricultural influence, but not much deeper. Usually, the sampling depth should be at least 30 cm for annual vegetation and 60 cm or more for perennial vegetation.

b *Division of cores into segments*

The number and length of core segments depends on the vertical heterogeneity of SOC in the profile. Generally, the greater the gradient, the shorter should be the core segments. Often, the length of segments increases with depth because the SOC is less dynamic and more uniform at depth. Where possible, core segments might be chosen to correspond roughly to clear demarcations in the profile, such as tillage depth or horizon boundary. To facilitate comparisons among a fixed soil volume it is preferable to have at least one common sampling depth, but this is not essential for comparisons among a fixed soil mass.

c *Core diameter and number per sampling point*

The preferred core diameter and number of cores per sampling point depend on the sensitivity required and the amount of soil needed for analysis. Sampling larger volumes of soil makes the sample more representative, but also increases cost and disturbance of the experimental area. Soil coring may not be feasible in stony soils that are impenetrable, but larger cores may effectively sample profiles containing some gravel.

d *Core refilling*

The soil void left after removing the sample can be filled by a soil core from an adjacent area (e.g., plot buffers), thereby preserving the physical integrity of the sampling site. This replacement, however, is labor-intensive and introduces soil from outside the treatment area which could affect subsequent samplings. Without intentional replacement, core voids become filled by adjacent topsoil, so subsequent cores should be positioned far enough away to avoid areas most affected by removal of previous cores, but close enough to exclude excessive spatial variations.

e *Core location relative to plants*

Proximity to plants may affect sample SOC contents, especially at the soil surface where plant C is concentrated at the crowns and under perennial or tap-rooted vegetation with localized plant C inputs to soil. Cores should be positioned to avoid bias, for example, when about 1/3 of the soil surface area is occupied by plants, three cores could be collected: one beneath plants, and two more between plant rows or crowns. Often basal areas occupied by the crowns of crops planted in rows are small ($\ll$30%) relative to the interrow areas, so samples are collected exclusively from the interrow. In other cases, such approximations may introduce considerable bias.

f *Measuring total soil C stocks*

In earlier studies of SOC, largely from the perspective of soil fertility, recent plant litter in the sample was often removed by sieving and discarded. In studies of C sinks, however, the total C stock should be measured. The procedure described above includes recent litter directly in the sample. An alternative approach is to analyze the plant debris separately, but include it in the calculation of C stocks. Above-ground residue, if present in significant amounts, may also need to be considered in calculating total C stocks (Peterson et al. 1998).

g *Contamination from other C sources*

Care should be taken to avoid introducing extraneous C from oil used as lubricant in soil coring tubes, wax in sample bags, and coatings on foil trays. The sample drying area should be free of dust (e.g., from plant sample processing), insects, and rodents. Cross contamination (e.g., between carbonate-rich subsoil and organic matter-rich surface soil) should be avoided during processing.

h *Repeated measurements of SOC over time*

Temporal changes in SOC can be measured with higher sensitivity if successive samples are removed from close proximity to (though not directly on) previous soil cores (Ellert et al. 2001; Conant et al. 2003; VandenBygaart 2006). To do that, the original sampling locations can be recorded using the GPS receiver, or by burying an electronic marker in one of the voids left by core removal. At subsequent sampling times, soil cores can then be taken immediately adjacent to previous cores, often in a grid pattern within ''microplots'' (Figure 3.3). The pattern may be modified to accommodate additional sampling times or other site conditions

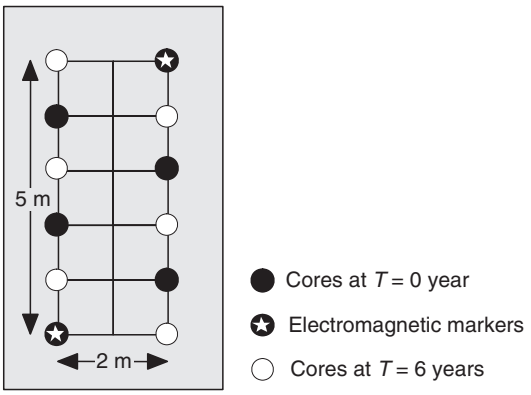

FIGURE 3.3. An example of the arrangement of soil cores within 4×7 m microplots intended for measuring temporal change in SOC stocks. (Adapted from Ellert, B.H., Janzen, H.H., and McConkey, B.G. in R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart, (Eds.), *Assessment Methods for Soil Carbon*, Lewis Publishers, Boca Raton, Florida, 2001.)

(Conant et al. 2003; VandenBygaart 2006). To most efficiently assess temporal changes in soil C stocks, the number of cores within each microsite and of microsites within a field or plot may be adjusted for differences in variability at the microsite and field levels (Bricklemyer et al. 2005).

3.4 ESTIMATING ORGANIC C STOCKS IN SOIL

3.4.1 MATERIALS

1 Fine soil grinder and small test sieves (No. 60 with 250 μm openings and No. 100 with 150 μm openings).

2 Carbon analyzer, using dry combustion and subsequent analysis of CO_2. (For information on analysis of total and organic C see Chapter 21.)

3.4.2 PROCEDURE

1 Obtain a representative subsample of the previously stored air-dry soil samples, ideally using ''drop through'' sample riffles or centrifugal sample dividers, as needed to avoid a biased subsample. Variability introduced by simpler, more expedient approaches (e.g., small scoops from six distinct areas within a thoroughly mixed tray of air-dried, <2 mm soil) is easily quantified by collecting multiple subsamples from a few samples. Scooping from the tops of sample bags or jars is not recommended, because soil constituents tend to separate during bag or jar filling and sample handling.

2 For most microanalytical techniques the coarsely ground (<2 mm) sample will have to be finely ground using a roller or jar mill, ball-and-capsule mill, shatter-box or ring-and-puck mill, or a mortar and pestle (e.g., Kelley 1994; Rondon and Thomas 1994; McGee et al. 1999; Arnold and Schepers 2004). The preferred fineness depends on the amount of sample analyzed. If less than 0.1 g is to be combusted, the sample should be ground to pass through a 150 μm sieve. The entire subsample should be ground to pass through the designated sieve (verified by testing a representative subset of samples rather than every sample). Finely ground samples can be stored in glass vials.

3 Dry samples and standards at 60°C to 70°C for 18 h, and determine the organic C concentration (g C kg^{-1} soil) (see Chapter 21). It is critical that inorganic C be completely removed before analysis by addition of acid, or that inorganic C be analyzed separately and then subtracted from total C concentration to estimate organic C concentration (see Chapter 21). Ideally certified reference materials should be used to verify analytical accuracy, but standard soils with certified values for total and organic C remain rare (Boone et al. 1999). At minimum, standard soils prepared in-house or obtained from a commercial supplier should be used to calibrate analyses and monitor analytical precision.

4 Express the concentration in units of mg C g^{-1} dry soil (=kg C Mg^{-1} = % × 10).

3.4.3 Calculations

The SOC stock is the amount of organic C in a fixed layer of soil per unit area of land. Typically, it is expressed in units of Mg C ha^{-1} to a specified depth. Alternative units include kg C m^{-2} = Mg C $ha^{-1} \times 0.100$. The simplest way to calculate SOC stocks is to accumulate the products of concentration and core density to a fixed soil depth and volume (see calculation below). But this approach is subject to bias when comparing SOC across space or time if core density varies even slightly (Ellert and Bettany 1995). For example, when comparing SOC stocks in two treatments, if the average core density to the specified depth is 1.10 Mg m^{-3} in treatment A and 1.00 Mg m^{-3} in treatment B, then the SOC stocks in treatment A will be biased upward because it has 10% more soil in the layers compared. For that reason, SOC stocks should be calculated on an ''equivalent mass'' or ''fixed mass'' basis (see calculation below), unless core densities are very uniform.

SOC Stocks (Fixed Depth)

$$\mathrm{SOC_{FD}} = \sum_{1}^{n} D_{cs} C_{cs} L_{cs} \times 0.1 \tag{3.4}$$

where SOC_{FD} is the SOC stock to a fixed depth (Mg C ha^{-1} to the specified depth), D_{cs} is the density of core segment (g cm^{-3}), C_{cs} is the organic C concentration of core segment (mg C g^{-1} dry soil), and L_{cs} is the length of core segment (cm).

SOC Stocks (Fixed Mass)

1 For all samples, calculate the mass of soil to the designated depth:

$$M_{soil} = \sum_{1}^{n} D_{cs} L_{cs} \times 100 \tag{3.5}$$

where M_{soil} is the mass of soil to a fixed depth (Mg ha^{-1}).

2 Select, as the reference, the lowest soil mass to the prescribed depth from all sampling sites (M_{ref}).

3 Calculate the soil mass to be subtracted from the deepest core segment so that mass of soil is equivalent in all sampling sites:

$$M_{ex} = M_{soil} - M_{ref} \tag{3.6}$$

where M_{ex} is the excess mass of soil, to be subtracted from deepest core segment.

4 For each sampling site, calculate SOC stock to fixed mass:

$$\mathrm{SOC_{FM}} = \mathrm{SOC_{FD}} - M_{ex} \times C_{sn}/1000 \tag{3.7}$$

where SOC_{FM} is the SOC stock for a fixed mass of M_{ref} and C_{sn} is the SOC concentration in deepest soil core segment (mg C g^{-1} dry soil) (core segment = n).

Sample Calculations

Given the following three hypothetical soil cores:

	SOC concentration (g C kg^{-1} soil)			Density (g cm^{-3})		
Depth (cm)	Core 1	Core 2	Core 3	Core 1	Core 2	Core 3
0–10	20.0	22.0	19.0	1.04	1.10	0.99
10–20	17.4	16.3	17.1	1.17	1.27	1.20
20–40	14.3	15.2	13.9	1.30	1.35	1.25
40–60	12.2	11.9	12.1	1.40	1.45	1.42

SOC_{FD} to 40 cm is
78.3, 85.9, and 74.1 Mg C ha^{-1} for cores 1, 2, and 3, respectively.

For SOC_{FM}:
M_{soil} = 4810, 5070, and 4690 Mg ha^{-1} to 40 cm, for cores 1, 2, and 3, respectively.
Hence:
M_{ref} = 4690 Mg ha^{-1} (mass of soil core 3), and
M_{ex} = 120, 380, and 0 Mg ha^{-1}, for cores 1, 2, and 3, respectively.

Thus:
For core 1, $SOC_{FM} = 78.3 - 120 \times 14.3/1000 = 76.6$ Mg C ha^{-1}.
Similarly, SOC_{FM} = 80.1 and 74.1 Mg C ha^{-1}, for cores 2 and 3, respectively.
Thicknesses of the fixed masses $= 40 - M_{ex}/(D_{cs} \times 100)$ = 39.1, 37.2, and 40.0 cm for cores 1, 2, and 3, respectively.

Comments

The approach described to estimate SOC stocks is applicable to sites where temporal changes are attributable to biological processes (chiefly the balance between soil C inputs and outputs), rather than geomorphic processes (soil erosion and deposition). The fundamental assumption is that soil mass is largely conserved among sampling times. At sites where this does not hold, other approaches are required to estimate lateral soil redistribution or net soil imports or exports, before temporal changes in SOC may be estimated. For example at sites with considerable mass additions or removals (e.g. waste application or soil export) survey techniques that enable sampling to a fixed subsurface elevation might be appropriate (Chang et al. 2007).

Numerous variations are possible in the calculation of SOC stocks by the ''fixed mass'' approach. For example, instead of using the SOC concentration of layer n in the correction (Equation 3.7), it may be more appropriate to use the weighted mean concentration in layers n and $n+1$. Or, rather than subtracting SOC in the correction, some researchers select a reference mass and *add* SOC, based on the SOC concentration of the layer below. In all cases, the method assumes that concentration value used is representative of the layer added or subtracted. For that reason, some researchers have used core configurations with a short segment just below the depth of interest. For example, if C stocks are to be estimated for the 0 to 20 cm layer, a 20 to 25 cm segment is isolated to be used for the ''fixed depth'' calculation.

Whether comparisons are based on a fixed soil depth or mass is immaterial for situations with soil redistribution, accumulation, or export. In such situations, it is practically impossible to distinguish between the effects of geomorphological processes (soil redistribution) and biological processes (plant C inputs and SOC decay). Only in rare instances (e.g., soils with a persistent and uniform marker layer, such as a fragipan) can soil deposition or erosion be inferred from routine soil sampling.

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