Science Societies

Sampling design for quantifying soil organic carbon stock in production ag fields

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Soil sampling for organic carbon concentration measurement is done the same as for soil fertility testing, so it should be very familiar: you will want to collect a composite soil sample to a fixed depth.

> The following article kicks off a new five-part series on assessing soil health. It seeks to provide a brief and practical review about measuring soil organic carbon (SOC), especially SOC stock. It is part of a larger Soil Science Society of America webinar series produced in partnership with The Soil Health Institute and sponsored by The Walton Family Foundation.

This is the first installment of a second round of the series titled “Assessing Soil Health.” As you all know, increasing soil organic carbon (SOC) is a co-benefit to improving soil health, and there are many emerging opportunities to directly monetize this benefit. As a CCA, I am sure you have been thinking about the opportunities and how your business model may fit into these markets. In this article, the goal is not to address the question of a business model in the markets—that is a longer discussion for another day—but to provide a brief and practical review about measuring SOC, especially SOC stock. Measuring SOC stock is a more expensive endeavor than measuring soil fertility levels, so carefully thinking through the components of the measurement is useful to your economic bottom line. Additionally, because of the importance of SOC and carbon changes, we recommended a high quality measurement. In this article, we define the FAO calculation of SOC stock, review the physical sampling technique, and discuss the effect of spatial variability on the outcome of a stock estimate.

First a brief recap of our previous Assessing Soil Health article on soil carbon measurement (**https://doi.org/10.1002/crso.20076**). For soil health assessment, SOC *concentration* is a measurement of total soil carbon concentration, by dry combustion. If the soil is calcareous (has free carbonates), a measurement of inorganic carbon concentration is subtracted from total carbon to get SOC. For soil health monitoring, a SOC concentration from 0 to 15 cm is adequate; however, voluntary carbon markets are evolving to require ***SOC stock*** estimates from 0- to 30-cm soil depths. This is where we start the conversation of measuring SOC stock.

Calculating Soil Organic C Stock

Just like other commodity markets, carbon marketplaces trade carbon in units of mass, typically using the metric unit of megagrams of carbon (Mg C). Subsequently, to quantify how much tradable carbon is in each field, we need to know the mass of carbon per unit area in a field. This mass of carbon per unit area is referred to as the SOC stock. Measuring a soil's carbon stock allows an apples-to-apples comparison to carbon emissions and carbon mass (as the greenhouse gas of CO_2) in the atmosphere.

Calculating soil carbon stock requires a measurement of the SOC concentration and bulk density of the soil. If you are sampling soils with coarse fragment volumes greater than 2%, you will also need an estimate of coarse fragment volume in the soil. Coarse fragments are the mineral components of soil that are larger than sand particles, or >2mm diameter. An influential and thorough discussion of SOC stock measurement can be found in the Food and Agriculture Organization of the United Nations document in the references below (FAO, **2019**). In short, SOC stock at a given depth is a function of carbon concentration (OC), bulk density, and coarse fragment (CF) measurement across a soil thickness or depth increment, as follows:

SOC stock (Mg C ha^{-1}) = OC [mg C g^{-1} soil] × bulk density [g cm^{-3}] × (1 – CF) + thickness of soil sample [cm] × 0.1.

In this equation, 0.1 is a conversion factor to get the units from those they are reported in by laboratories (mg C cm^{-2}) to Mg C ha^{-1}. For completeness, please note that CF is volumetric coarse fragment content and bulk density is the bulk density of the fine soil component. Bulk density equals (bulk soil mass [g] – coarse fragment mass [g])/(bulk soil volume [cm^3] – coarse fragment volume [cm^3]).

Collecting the Soil Sample

Carbon Concentration

With the calculation behind us, let us focus on collecting the samples. Soil sampling for organic carbon concentration measurement is done the same as for soil fertility testing, so it should be very familiar: you will want to collect a composite soil sample to a fixed depth. The goal of composite sampling is to get a representative soil sample (one that is not impacted by random variation is SOC concentrations).

Composite sampling consists of collecting multiple cores in a fixed area and mixing these cores into a single sample for laboratory analysis. You want to make sure the area you collect the soil cores from has homogenous soil (i.e., same soil series, same slope, same management zone, etc.). As a starting point, collecting your composite sample within a 15-ft radius circle would suit most needs as this area will have relatively homogenous soils in most landscapes.

The number of cores that represent the composite is another decision point. A rule of thumb is to use 10 to 20 cores per composite. Generally, as the local variability of the soil increases, more cores are needed to get a representative sample. For example, the following situations represent least to most local SOC variability: well-tilled Ap horizon, 20-year no-till, never-tilled pasture/forest land, and soils with coarse fragments. In the more variable management scenarios, consider collecting more soil cores in your composite sample.

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Bulk Density

Sampling for bulk density feels daunting for many reasons, one being the need to pound a slide hammer to get a soil-coring device into the ground. Nonetheless, it is worth remembering that taking the time to make a careful, quality, soil volume measurement pays off when stocks are calculated. Bulk density is a value that ranges from roughly 0.85 g cm^{-3} in a freshly tilled soil to 1.60 g cm^{-3} in a compacted, root-limited soil. In most row-crop landscapes that are not freshly tilled (measuring freshly tilled soils is fraught with frustration), median bulk densities of the top 30 cm will range from 1.0 to 1.35 g cm^{-3}. Bulk density can be changed by management. For example, in the North American Project to Evaluate Soil Health Measurements (or NAPESHM), soils at a 0- to 15-cm depth and with less tillage had, on average, 2% less bulk density values than soils treated with more tillage.

To sample bulk density, you will need to collect a known mass of soil and calculate the oven-dry soil mass. While there are multiple ways to collect a known soil mass, the most common involve inserting a large soil core into the ground and extracting the soil from the core. Because these soil cores need to be large, you will also need a method to drive the soil into the ground such as a slide hammer or hydraulic coring machine. The main challenge to bulk density sampling is to avoid compacting the soil while collecting your sample so that you don't have artificially high bulk density readings. Tricks to getting good bulk density include (a) sampling no wetter than field capacity (slightly drier than field capacity is ideal for many soils), (b) not sampling after a recent tillage, (c) using the largest feasible diameter soil core (The Soil Health Institute uses a 3-inch corer; less than 2 inches gets difficult), and (d) keeping depth increments small (15 cm is a good compromise). Bulk density sampling equipment includes a soil core and a means of pushing the core into the ground—a hydraulic probe or a slide hammer. The Soil Health Institute recommends collecting two depths, rather than one—0 to 15 and 15 to 30 cm.

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Due to the labor-intensive nature of bulk density sampling, it is not practical to take 10 to 20 bulk density measurements to pair with a composite SOC concentration sample. As a compromise, stakeholders measuring agricultural carbon stocks are generally collecting one bulk density core paired with each composite core; some are sampling fewer bulk density cores per composite sample. With current information, it seems reasonable to collect one core to pair with the composite sample. Only collecting one bulk density core amplifies the importance of taking extra care when pulling the sample to not compact the soil core and to accurately record the volume of soil extracted.

Coarse Fragments

There is nothing harder to adequately quantify in a soil landscape than coarse fragments. In a recent review of global digital soil-mapping efforts, coarse fragments were determined to be the hardest to estimate and to map (Chen et al., 2021). Those of you soil sampling in loess (wind-blown) soil are lucky not to have to deal with coarse fragments. Again, there is a balance between sampling and lab expenses and measuring precision. When coarse fragments are present but do not hinder collection of an intact bulk density core, then the core method is adequate, and the sampler must decide if multiple cores improve the accuracy of the coarse fragment estimate. If soil has so many coarse fragments that a core cannot be pounded in, an excavation method will need to be employed (Grossman & Reinsch, 2002).

Spatial Soil-Sampling Design

Compared with routine soil fertility sampling, sampling for soil carbon stocks is more expensive. Generally, the samples are more labor intensive to collect (particularly bulk density), and the laboratory analysis for SOC concentration is also more expensive than standard fertility tests. Due to this increased cost, it becomes very important to select a sampling methodology that optimizes the return on investment of your sampling. While you may be able to collect adequate SOC stock estimates from traditional whole-field sampling or grid-sampling approaches, most soil carbon sampling approaches recommend a stratified random sampling approach (e.g., Climate Action Reserve Soil Enrichment Protocol; **www.climateactionreserve.org/how/protocols/soil-enrichment**).

The number of samples in an area is an important consideration. More samples result in better measurement but add cost, so you will need to make an agronomic and business decision as to how many samples you want to collect.

In a stratified random sampling approach, the field is broken into large areas (greater than 5–10 acres) where the soil is mostly unform (i.e., same soil series, same management, etc.). Good starting points for sampling strata/areas include soil survey polygons or management zones. Within these zones, several individual stock samples are collected. To get good coverage of the area without introducing any bias, the location of samples is chosen at random within the area (hence the random in stratified random). The number of samples in an area is an important consideration. More samples result in better measurement but add cost, so you will need to make an agronomic and business decision as to how many samples you want to collect.

As a general guideline, as the size of the area increases, the number samples within the area should increase. While there are not fixed rules on the spatial density of samples, most recommendations are targeting a sample density of one sample per 5 to 10 acres. If you do not collect enough samples, it may be difficult to enroll in some marketplaces or exchanges that require minimum sample densities, so check with the program you are seeking to enroll credits for their specific requirements. It may be prudent (at first) to err on the side to too many samples (i.e., densities less than one sample per 5 acres) to ensure your credits are compatible with marketplace standards.

Summary

Measuring SOC stock requires careful consideration of cost of sampling, value of the measurement, and spatial extent of the area to be represented by the measurement. To get a stock estimate at any one location, SOC concentration of the soil, bulk density, and coarse fragment content need to be measured. Each measurement has it challenges in a balance of labor, getting a representative sample, and not shipping too much soil back to the lab. In addition to taking the sample, spatial placement of the SOC stock measurements is also a consideration as soil C varies considerably across landscapes. If interested in soil sampling to enroll in a marketplace, be sure to follow the specific sampling requirements of the program with which you are seeking to enroll credits.

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