Soil carbon calculations

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How much carbon is really stored beneath your feet? This article explains how soil scientists measure and calculate soil carbon stocks, revealing why factors like soil depth, texture, and land use can dramatically influence carbon storage—and why perennial pastures often hold an advantage over cropland.

This article is part of the series titled, "Soil Carbon in the Carolinas." It is adapted from a series that originally was published in *The Carolina Cattle Connection.* While regional soils, climate, and farm data from North and South Carolina are used as primary examples, readers outside the Carolinas will still find it highly useful, especially for understanding soil health, interpreting soil carbon data, and advising on management practices that build resilience.

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How much carbon is being stored in the soil on a Carolina farm? This relatively simple question could be answered quickly with the following: "not very much," if we accept the general premise that soils in the southeastern U.S. are relatively poor and have little potential to accumulate soil organic matter. However, if we were to start collecting soil in a strategic manner, then we might discover the quantity of carbon in soil is greater than previously thought. A more thorough answer to this question will be explored in this article.

Accounting for carbon in soil requires that samples be collected to represent the land uses on a farm. Carbon will vary based on geographic location in the region, soil type and texture, soil depth, and current and historical land management. Within a single farm, you might think there won't be so much variation in these factors, but in fact, there can be as much variation in soil carbon due to these factors on one farm as there is among different farms. Let's dig into how soil carbon varies.

Factors that influence soil carbon

Soil texture can have a large influence on soil carbon. As described in last month's article in this series, carbon content of sandy Coastal Plain soils is often less than in loamy and clayey soils of the Piedmont and Blue Ridge. This is because sandy soils have limited soil aggregation and affinity to absorb organic molecules. These organic molecules are then more accessible by the abundant microorganisms (bacteria and fungi) living in soil, and therefore, more susceptible to decomposition, leading to lower levels of soil organic matter (58% of which is carbon). Indeed, soil texture can have a large impact on soil carbon retention. Just note that landscape position and geographic region can significantly alter this generalization.

Soil depth has a large influence on soil organic carbon concentration in most soils. The greatest concentration will be near the soil surface and will decline with increasing depth. The extent of decline with depth may depend on how much surface soil carbon had accumulated in the past. Surface accumulation of soil carbon is largely controlled by the type of land use and management. More plant material that is returned to soil can lead to greater soil carbon. Soils that are not disturbed for decades will typically have greater carbon concentration than disturbed soils. Mixing soil with tillage or land disturbances creates opportunities for soil microorganisms to access a wider variety of substrates and for organic particles to be fractured into smaller pieces for faster decomposition.

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How to measure and calculate soil carbon stocks

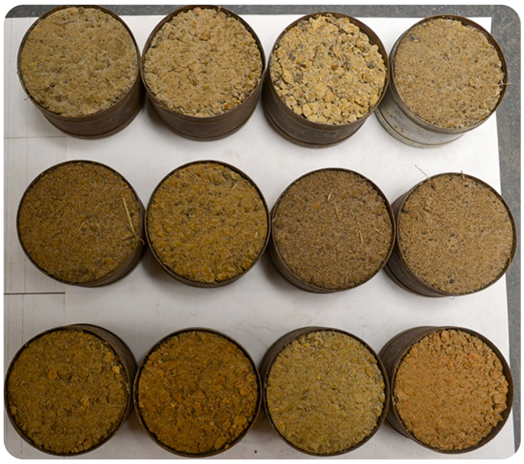
Samples of soil collected from a farm can then be analyzed for total carbon. Since most soils are acidic or slightly acidic in the region, total carbon can be considered the same as organic carbon. Carbon concentration of a small soil sample is determined in a precision instrument that determines the amount of carbon dioxide released during combustion (burning the sample). Getting good estimates of soil carbon requires a representative sample of the field of influence. Precision is needed in sampling the depth of interest only, such as 0 to 4 inches typically for perennial pastures in the region. However to determine the stock of carbon in soil, many scientists have agreed that we should determine values for the top foot of soil. It is then necessary to get precise samples from more than one depth, such as 0 to 4 inches, 4 to 8 inches, and 8 to 12 inches. Other depth increments can also be used, but the key is to get samples from throughout the top foot.

Getting good estimates of soil carbon requires a representative sample of the field of influence.

Getting a representative soil sample will also need to consider expected soil variations despite having managed a field uniformly over time. A soil survey map can help to divide fields into separate sampling units whenever soil texture and slope characteristics might be assumed to influence results. A representative sample should be collected from a composite of multiple soil cores. Typically, with a ¾-inch or 1-inch diameter soil probe, a dozen cores are recommended to be collected and composited into a single sample to represent a field or a portion of a field.

The number of unique samples to collect on any one farm to get an accurate accounting of soil carbon will depend on overall goals, time available for sampling, and cost considerations. Cropland, pastures, woodlands, and farmyards are unique land uses and should be considered for separate analyses. Likely there may be distinct historical management conditions from some pastures on a farm, and so these fields should be sampled separately as well. Again, if there are landscape variations within these unique land uses, then a field may be divided into smaller sections.

Soil carbon concentration can be expressed in percent carbon of total soil mass (parts per hundred). In scientific publications, carbon concentration is usually presented as grams of carbon per kilogram of soil (g/kg) (parts per thousand). As an example, a value of 25 g carbon/kg soil is equivalent to 2.5% carbon.



Soil carbon calculations begin with carefully collected soil samples. Differences in soil structure and organic matter can influence both carbon concentration and bulk density.

To calculate carbon content, soil carbon concentration must be multiplied by the bulk density of soil and the depth increment of interest. Bulk density is the mass of soil in a standard volume of soil. Typical values of agricultural soils will vary from 1.0 megagram (Mg) of soil per cubic meter (m^3) to 1.5 Mg/m^3. Bulk density may be influenced by recent tillage that loosens soil, by soil organic matter accumulation that loosened soil over time, or by cattle or tractor traffic that compacts soil. When soil organic matter is high, bulk density is typically low. When soil organic matter is low, bulk density is typically high.

An example calculation of soil carbon content follows. A field planted to annual forages after decades of grain production had soil organic carbon concentration at a depth of 0 to 4 inches (translates to 0.1 meters or 10 centimeters) of 16 g/kg and bulk density of 1.41 Mg/m^3. At a depth of 4 to 12 inches, soil organic carbon was 8 g/kg and bulk density was 1.48 Mg/m^3. Therefore, soil carbon content within the top foot of soil can be calculated as the summation of the two depth increments, as shown in Table 1.

Table 1. Example calculation of soil carbon content from samples collected at two depth increments.

0-to-4-inch depth

16 g/kg x 1.41 Mg/m^3 x 0.1 m x 1 kg/1000 g x 10,000 m^2/ha = 22.56 Mg C/ha

4-to-12-inch depth

8 g/kg x 1.48 Mg/m^3 x 0.2 m x 1 kg/1000 g x 10,000 m^2/ha = 23.68 Mg C/ha

Sum of two depths (0-to-12-inch depth)

22.56 Mg C/ha + 23.68 Mg C/ha = 46.2 Mg C/ha

Note: C=carbon, g=gram, ha=hectare, kg=kilogram, m=meter, m2=square meter, m3=cubic meter, and Mg=megagram.

This example helps to illustrate how important the enriched layer of the top 4 inches of soil can be to the accumulation of soil organic carbon. With twice the concentration of soil organic carbon in the top 4 inches as at 4 to 12 inches, soil organic carbon was nearly doubled in the top foot of soil despite the 4-inch layer only occupying one-third of the top foot layer.

Common accounting figures of carbon are often translated into metric tons of CO_2 per acre (Mt CO_2/ac). One Mg C/ha is equal to 1.5 Mt CO_2/ac. In the example annual pasture in Table 1, 46.2 Mg C/ha would translate to 69.3 Mt CO_2/ac.

Perennial pasture can store significant amounts of soil carbon.

If the annual pasture were to occupy 35 ac on the farm, then soil organic carbon under this annual pasture would total 2352 Mt CO_2 /ac. For comparison, a typical house in the United States is considered to contain 100 Mt CO_2, owing to the wooden materials used in its construction. Therefore, the 35-ac annual pasture would contain 23.5 times the carbon contained within a typical house.

Let's now consider the average soil organic carbon and bulk densities observed in a study across 25 research stations in North Carolina. All relevant data like the annual pasture example are shown in Table 2. Because of the much greater soil carbon in the surface 4 inches of the pasture compared with the cropland, soil carbon stock in the top foot of the soil profile was also greater. For example, a 10-ac farm with perennial pasture would contain an average of 1100 Mt CO_2. A 10-ac farm with cropland would contain 822 Mt CO_2. The difference between these two farms would be 278 Mt CO_2, or 34% more soil carbon in the top foot of soil under pasture than under cropland. These data and calculations indicate that perennial pastures are an important land use that can store significantly greater amounts of carbon than cropland. The bottom line is that perennial pastures should be considered an important land use for storing soil carbon.

Table 2. Average soil carbon content under conventional-till cropland (88 fields) and grassland (98 fields) in North Carolina.

Land use and soil depth	Soil organic carbon (g/kg)	Bulk density (Mg/m^3)	Carbon content (Mg C/ha)	Carbon content (Mt CO_2/ac)
Cropland				
0 to 4 inches	16.2	1.43	23.2	34.7
4 to 8 inches	11.8	1.49	17.6	26.4
8 to 12 inches	9.2	1.53	14.1	21.1
0 to 12 inches	12.3	1.48	54.9	82.2
Grassland				
0 to 4 inches	30.8	1.18	36.3	54.5
4 to 8 inches	15.1	1.43	21.6	32.4
8 to 12 inches	10.1	1.52	15.4	23.1
0 to 12 inches	17.7	1.38	73.3	110.0

Note: Soil carbon content difference at a depth of 0 to 12 inches between grassland and cropland was 27.8 Mt CO_2/ac (38% greater).

In the next article of this series, we'll go over some more numbers to show how much carbon is being stored under forage and grazing lands from some of clients' farms in different parts of North Carolina.

Self-study CEU quiz

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1. When collecting a representative soil sample from a field, about how many soil cores are typically recommended for a composite sample?

a. Four.

b. Eight.

c. Twelve.

d. Twenty.

2. A soil carbon concentration of 25 g C/kg soil is equivalent to which carbon percentage?

a. 0.25%.

b. 2.5%

c. 12.5%.

d. 25%.

3. Which land use had the greater average soil carbon content in the top 12 inches of soil in the North Carolina study?

a. Conventional-till cropland

b Grassland (perennial pasture)

c. Forestland

d. Farmyard areas

4. Using the conversion in the article, if a soil contains 20 Mg C/ha, approximately how much CO_2 would that represent?

a. 13 Mt CO_2/ac.

b. 20 Mt CO_2/ac.

c. 30 Mt CO_2/ac.

d. 45 Mt CO_2/ac.

5. According to the article, why can total carbon be considered the same as organic carbon in most soils of the region?

a. Most soils are highly alkaline.

b. Most soils contain little clay.

c. Most soils have been tilled recently.

d. Most soils are acidic or slightly acidic.

This quiz was drafted with AI assistance and reviewed by the editorial team for accuracy and appropriateness.

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