



Storage of soil carbon in the Carolinas

By Alan Franzluebbers

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Suspensions of soil from different farms in North Carolina to determine clay concentration



This article is the first in a new 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.

This first article in the series highlights how soil carbon improves physical structure, nutrient retention, water availability, and biological activity, making soils more resilient and fertile. It also shows that soil carbon varies with depth, texture, and region, and that good forage and grazing management can significantly increase soil carbon storage and help address climate challenges.

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What is soil carbon? Carbon in soils of the Carolinas is composed mostly of organic carbon, as contrasted with high levels of inorganic carbon from carbonates or caliche in the western USA. Organic carbon was once in living plants and animals and has since been transformed by soil microorganisms to form organic matter in soil. Soil organic matter is composed mostly of carbon. In fact, carbon makes up 58% of soil organic matter, and nitrogen makes up about 5% of soil organic matter. These two elements are measured in most analytical labs to determine the percentage of soil organic matter. The hundreds of billions of individual bacteria and fungi in a teaspoon of soil are composed of carbon. However, the non-living component of soil contains most soil organic carbon. Non-living components of soil carbon can be in small organic matter pieces called particulate organic matter, in dissolved organic matter that makes standing water turn the color of tea, in humic matter that is highly stable and doesn't break down easily, and in various inert organic components such as charcoal following burning of plant biomass.

Why is soil carbon important? It is a vital component of ecosystem properties, processes, and functions. These features are explained below. Importantly, this relatively small organic component of soil provides many of the features needed to make soil healthy and functioning to its natural potential capacity. Healthy soil makes an excellent growing medium for crops and pastures and helps to protect the environment and provide ecosystem stability.



Bermudagrass pasture during winter in Pitt County, North Carolina.

What are some physical features of soil carbon? Carbon gives soil a dark color to absorb heat. Soil carbon has low solubility, ensuring that organic matter inputs are retained and not rapidly leached from the soil profile. Soil with high carbon content acts like a sponge to retain more water for plant growth, and it stabilizes soil structure to provide pore space for microorganisms (bacteria and fungi) and various soil critters (earthworms, beetles, and spiders).

What are some chemical features of soil carbon? Soil with high carbon content increases cation exchange capacity to retain cations like calcium, magnesium, ammonium, iron, and aluminum. Soil carbon buffers against pH swings to keep acidity in a more acceptable range for plants. Soil organic matter complexes metals to enhance dissolution of some minerals, enhances availability of phosphorus, reduces loss of micronutrients, and reduces toxicity of heavy metals. Soil organic matter can alter the biodegradability, activity, and persistence of pesticides applied to soil or that get into soil.

What are some biological features of soil carbon? Soil carbon in organic matter offers a reservoir of energy to drive biological processes. Soil organic matter encapsulates various plant-essential nutrients in a long-term storage condition. However, these nutrients are slowly released to plants through soil microbial activity, i.e., bacteria and fungi that feed on this organic matter. Soil carbon can both enhance and inhibit enzymes that transform plant-available nutrients. High soil carbon content provides



Unrolling hay on winter pasture in Watauga County, North Carolina.

ecosystem resilience, enhancing the ability to recover from various disturbances, such as from drought, flooding, tillage, and fire.

What does forage have to do with soil carbon? More and more research has been documenting how improved forage and grazing land management significantly increases soil carbon, thereby promoting greater soil health features and improved ecosystem resilience. Climate changes threaten ecosystem resilience. Managing soils with greater soil carbon content will help farmers limit the negative consequences of climate change. Better forage management, therefore, can be viewed as an effective adaptation strategy to climate change. Additionally, better forage management with increasing soil carbon content can be considered a climate-change mitigation strategy when deployed over large areas. This is because carbon dioxide in the atmosphere is transferred to fixed carbon stored in soil organic matter.

Just a reminder that soil organic matter is the primary source of carbon in Carolina soils. Table 1 lists some common concentrations in different units that you may see in publications.

Table 1. Common soil carbon concentrations in relation to percent soil organic matter.

Soil organic matter (%)	Carbon (%)	Carbon (g/kg)
0.5	0.3	2.9
1	0.6	5.8
1.5	0.9	8.7
2	1.2	11.6
3	1.7	17.4
4	2.3	23.2
5	2.9	29.0

Soil organic matter (%)	Carbon (%)	Carbon (g/kg)
6	3.5	34.8
8	4.6	46.4
10	5.8	58.0

% is parts per hundred (1/100)

g/kg is parts per thousand (1/1000)

Table 2. Average percent soil carbon concentration under grasslands throughout North Carolina.

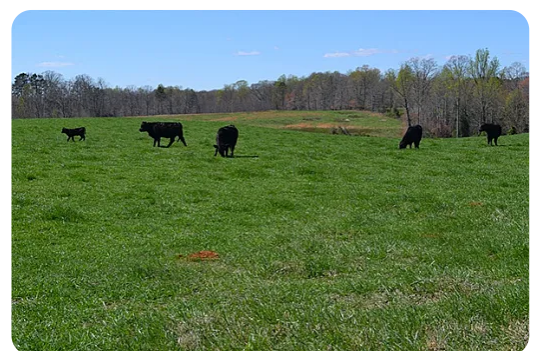
Soil depth (inches)	Soil carbon (%)
0–2	4.1
2–4	2.3
4–6	1.4
6–8	1.0
8–10	0.7
10–12	0.6
0- to 6-inch average	2.5
0- to 12-inch average	1.5

Carbon concentration of Carolina soils varies considerably. This variation is primarily a function of soil depth. Carbon is most often concentrated near the soil surface. When probing deeper into the soil profile one will find less and less soil carbon on a concentration basis. The average soil carbon concentration at different depth increments

is shown in Table 2. Soil carbon declined much more with each initial increment below the soil surface, but then there were smaller declines deeper in the profile. This is a typical depth distribution of organic matter all around the world. In other words, soil organic matter concentration follows a non-linear decline or a logarithmic decline with depth.

Not only does soil carbon vary with soil depth, but also because of differences among physiographic regions. North and South Carolina share the same physiographic regions of the relatively flat Coastal Plain, the hilly Piedmont, and the Blue Ridge mountains. In general, soils in the Coastal Plain are coarse textured with mostly sand and little silt and clay-sized particles. Soils in the Piedmont and Blue Ridge can also be sandy but are more often fine textured. Clay particles are very small and technically defined as less than 2 micrometers in diameter (a micrometer is 1/1,000 of a millimeter). Sand particles are greater than 53 micrometers in diameter. Silt particles have diameter of 2 to 52 micrometers. Because of their small size, clay and silt have electrostatic charges and are chemically reactive. This allows the particles to aggregate. Sand particles do not have much reactivity, and therefore, do not aggregate readily. Soils with significant quantities of clay and silt will form strong aggregates that are even more strengthened with increasing soil organic matter concentration.

Soil texture is a key factor affecting soil carbon concentration because of the ability of clay and silt particles to attract organic matter and encase it in stable aggregates that also physically protect organic matter from decomposition. This means that soil bacteria and fungi have more difficulty in



Early spring grazing on tall fescue in Lincoln County, North Carolina.

accessing these organic resources. Therefore, fine-textured soils are often observed to store more carbon than coarse-textured soils. However, management of soils can sometimes override these physical regulators.

Soil was collected on multiple pasture-based livestock farms in North Carolina in 2023. This included 108 samples in the Coastal Plain region, 394 samples in the Piedmont region, and 146 samples in the Blue Ridge region. Table 3 reports the average soil carbon concentration in these three regions as a function of sampling depth. Again, carbon concentrations were highly dependent on soil depth in all three regions. In addition, the elevation gradient rising from the coast to the mountains led to greater soil carbon concentrations. This effect is partly due to (1) elevation that controls mean annual temperature (warmer in the Coastal Plain and cooler in the Blue Ridge) and (2) soil texture differences. There may also be some forage species differences that contributed. Management differences among farms will be the focus of a future issue of this series.

Table 3. Average percent soil carbon concentration under grasslands in different regions of North Carolina.

Soil depth (inches)	Coastal Plain	Piedmont	Blue Ridge
0–2	2.9	4.3	4.4
2–4	1.7	2.3	2.8
4–6	1.1	1.4	1.8
6–8	0.8	0.9	1.3
8–10	0.6	0.7	1.0
10–12	0.5	0.5	0.9
0- to 6-inch average	1.8	2.5	2.9

Soil depth (inches)	Coastal Plain	Piedmont	Blue Ridge
0- to 12-inch average	1.2	1.5	1.9

The average soil carbon concentrations at the 0-to 6-inch depth in Table 3 translate to 3.2% soil organic matter in the Coastal Plain, 4.4% soil organic matter in the Piedmont, and 5.0% soil organic matter in the Blue Ridge. These values are nothing to sneeze at, especially when we are typically reminded that soils in the Carolinas are relatively poor, for example less than 1%. The key here is that most soil samples were collected under decades of pasture management. If one samples deeper than the surface 6 inches, then soil organic matter concentrations will be much lower. The average percent soil organic matter at the 6- to 12-inch depth was 1.1% in the Coastal Plain, 1.2% in the Piedmont, and 1.8% in the Blue Ridge.

In summary, carbon gives soil its vitality. Stabilized in soil as organic matter, it helps store abundant plant-available nutrients, it loosens soil to allow rapid water infiltration and hold more water over time, and it provides the needed resources for soil microorganisms to be actively transforming soil into a fertile substrate. Carbon in soil is concentrated near the soil surface where it can provide the greatest benefit to the plants it nourishes

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1. Which of the following is NOT true? Soil with high carbon content_____.

- a. decreases cation exchange capacity.
- b. alters the biodegradability, activity, and persistence of pesticides.
- c. buffers against pH swings.
- d. complexes metals.

2. What role does temperature play in soil carbon storage across regions?

- a. Higher temperatures increase long-term carbon storage.
- b. Lower temperatures slow decomposition and help preserve carbon.
- c. Greater temperature variability increases long-term carbon storage.
- d. Temperature has no measurable effect on soil carbon levels.

3. How does soil carbon concentration typically change with depth in the soil profile?

- a. It remains relatively constant at all depths.
- b. It increases steadily with depth due to compaction.
- c. It declines sharply near the surface and more gradually deeper down.
- d. None of the above.

4. Which physiographic region of North Carolina typically has the highest soil carbon concentrations?

- a. Blue Ridge.
- b. Coastal Plain.
- c. Piedmont.

d. Barrier islands.

5. The article lists several factors that cause one of the physiographic regions mentioned in Question 4 to have the highest soil carbon. Which factor was NOT mentioned?

a. Forage species differences.

b. Soil texture differences.

c. Elevation differences.

d. Soil pH differences.

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