Science Societies

Soil carbon distinguished from pedogenesis and management

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October 2, 2026

Soil carbon measurements can be misleading if inherent soil differences aren't considered. Learn how deep-profile sampling and a "root-zone enrichment" approach help separate management effects from natural soil characteristics, providing a clearer picture of carbon gains under grassland management.

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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Pedogenesis is the process of soil formation. This process manifests itself into the soils we know today after thousands or millions of years of weathering. The formation of

soils is influenced by five key factors: (1) parent material, (2) climate, (3) topography or relief, (4) organisms, and (5) time. In case you don't have enough abbreviations on your daily calendar, these five factors are abbreviated by soil scientists as CLORPT. This stands for climate (CL), organisms (O), relief (R), parent material (P), and time (T). Pedogenesis describes the historical processes that ultimately resulted in the soil profiles typical within the Coastal Plain, Piedmont, and Blue Ridge regions of the Carolinas. The parent material of Coastal Plain soils is from marine deposits of sand and clay. The parent material of Piedmont soils is typically from weathered bedrock of saprolite, which is a Greek term for "rotten rock" since underlying rocks were chemically weathered over time into smaller fragments. The parent material of Blue Ridge soils varies depending on the presence of igneous, metamorphic, and sedimentary rock outcropping.

Pedogenesis is an important part of describing soil carbon because carbon provides a mechanism for rock weathering by feeding soil microorganisms that catalyze chemical reactions to disintegrate rocks. Soil microorganisms, plants, and a variety of soil-dwelling animals are the organisms that help form soil over time. Carbon also accumulates in soil differently depending on the mineral features of soil profiles. The amount of carbon stored in your soil is partly due to pedogenesis and partly due to how you and your forefathers managed the land. The process of pedogenesis provides some limitations as to how much carbon can be stored in soil, mostly because of the type of minerals and their size (think clay, silt, and sand particles) and the overall climate (think warm and wet rather than cool and dry).

Decisions about livestock, forage, and grazing are all forms of land management.

Management is what you do on the land over time. Planting a stand of tall fescue is a type of management. The type of livestock you have on your farm is a type of management. Whether forage is grazed directly by ruminant livestock or cut for hay and fed elsewhere differentiates two styles of management. Allowing cattle to occupy the same pasture the entire year or corralling them to graze on smaller parcels of land with electrified poly-wire fencing and frequently moving them to fresh forage is a differentiation of management styles. How long livestock have been on your farm is a duration of management, which has impacts on soil carbon too.

Now that we have some definition and description of pedogenesis and management, this story of soil carbon gets more complicated, but also a whole lot more interesting! Consider that pedogenesis took millions of years to result in the soil that you or your forefathers obtained and managed. You might think that your relatively short presence on the land might not have much effect on soil carbon. This speculation sets the basis for a lot of the agroecosystem research we conduct in the Carolinas, in this country, and around the world. Land-based agricultural science often tests whether our intuitions are correct or not.

So, let's test this notion that soil carbon can be separated by the influences of pedogenesis and management. There might be different ways of testing this hypothesis. An obvious one would be to deploy a standard type of management onto at least two contrasting soils with different climate, organisms, relief, parent material, and time—yes, I wanted to say CLORPT! We might consider planting tall fescue into

fields at the Upper Coastal Plain Research Station in Rocky Mount, NC; the Piedmont Research Station in Salisbury, NC; and the Mountain Research Station in Waynesville, NC to put the same management on three different types of soils differentiated by climate. What was done to each of these fields for the past several decades might be an important consideration and hopefully those conditions were similar.

We would want to sample soil today and then perhaps periodically every 5 to 10 years thereafter for up to 30 to 50 years until there would be no further change in soil organic carbon. We could then calculate which soil had the lowest and highest soil organic carbon at the beginning and the end of the experiment. This might tell us which region allowed the greatest stock of soil carbon to occur as a test of the pedogenesis effect.

We could also calculate what the difference in soil organic carbon was between the ending and beginning of the experiment and that could tell us which region allowed the greatest accumulation. This could also tell us what the effect of management was from the planting of tall fescue. This long-term experimental approach would be considered typical for how land management would be evaluated.

But we might only deploy one type of forage utilization strategy, such as cutting for hay and have no information on what the effect of grazing might be under these conditions. If we wanted to know something about fertilization effects on soil, then we'd have to repeat observations at the same locations, and this would take more space and create more work. It takes time and resources to get good data. These are also the reasons why we don't have much information on long-term management effects on soil carbon; it takes time and money, as well as people dedicated to the process!

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Let's consider an alternative approach. By sampling deeper into the soil profile, such as 24 inches deep, soil analyses can reveal to us something about pedogenesis and management at the same time. The primary rooting zone of most plants will be the upper 12 inches of soil. When we sample deeper than 12 inches, there is often little detectable change in soil organic carbon over time. Using this information to our advantage, we could then use the carbon concentration at the 12-inch depth to indicate the pedogenesis influence without management influence. The changes in soil carbon within the surface 12 inches can then be attributed to land management, as long as we account for the profile-specific pedogenesis influence from the carbon concentration at the 12-inch depth. This approach is what I call "root-zone enrichment of soil organic carbon," that is the accumulation of soil carbon in the surface 12 inches (the primary root zone) minus that of a baseline condition dictated by pedogenesis.

Deep-profile soil sampling helps distinguish management effects from inherent soil characteristics.

Results for root-zone enrichment of soil organic carbon are presented in the following using samples collected at depths of 0-4 inches, 4-12 inches, and 12-24 inches from paired grassland and cropland management at different research stations throughout North Carolina in 2021. Baseline soil organic carbon was not different between pairs of land use within a grouped location (four groups shown in Figure 1). Baseline soil organic carbon varied dramatically among the four groups, which can be assumed to have had different soil formation factors influencing these soil carbon levels.

Root-zone enrichment of soil organic carbon was greater under grassland than under conventional-till cropland in each of the four soil groups. On average, root-zone enrichment of soil organic carbon was 13.1 tons/ac under grassland and 4.8 tons/ac under conventional-till cropland. That's an average difference of 8.3 tons/ac. Root-zone enrichment was not proportional to the total stock of soil organic carbon but rather was a relatively constant quantity independent of baseline soil condition. Total stock of soil organic carbon would be equal to the sum of baseline soil organic carbon and root-zone enrichment of soil organic carbon. Total stock of soil organic carbon averaged 14.1 tons/ac in the low group, 17.7 tons/ac in the medium group, 24.8 tons/ac in the high group, and 39.6 tons/ac in the very high group.

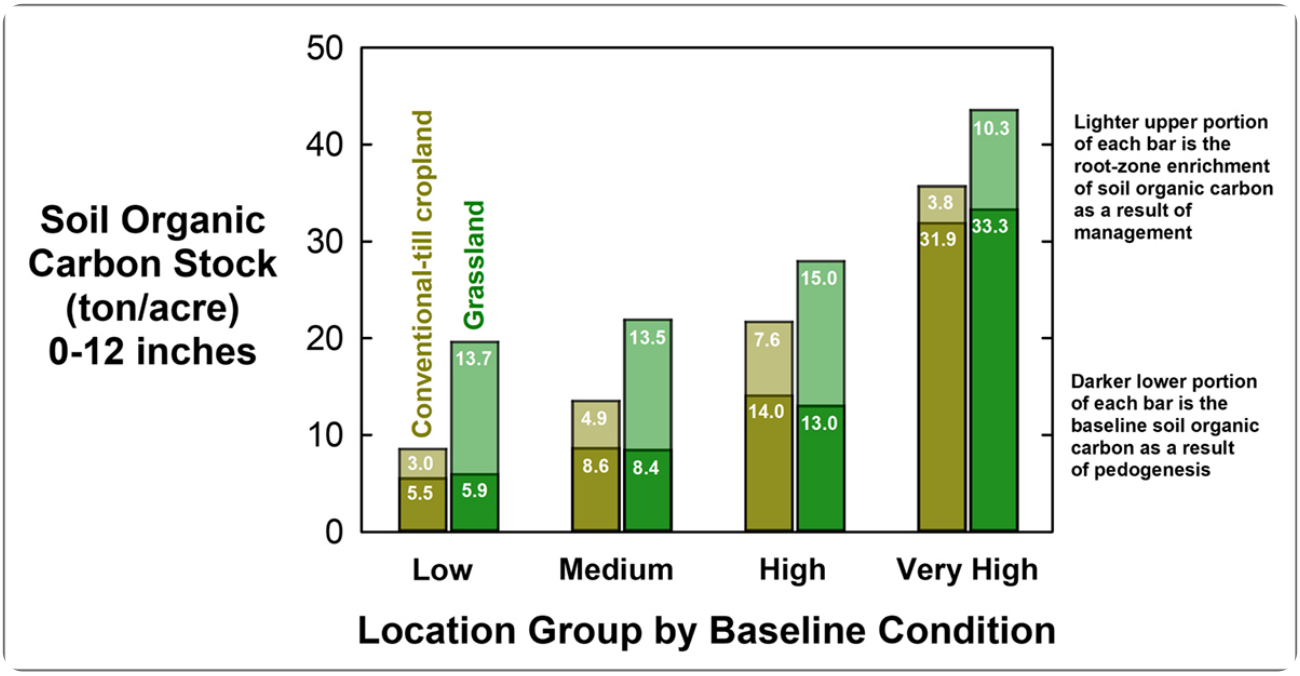

Figure 1. Average soil organic carbon stocks as affected by soil group (four conditions), source of formation (pedogenesis or management), and land use (conventional-till cropland or grassland).

These results of root-zone enrichment illustrated that grassland could store more soil organic carbon than conventional-till cropland, irrespective of the baseline soil condition. If you recall from the last article of this series, total soil organic carbon across private forage and grazing lands in North Carolina averaged 22.3 tons/ac in the Coastal Plain region and 32.4 tons/ac in the Blue Ridge region. Therefore, could the lower total stock of soil organic carbon in the Coastal Plain region compared with the Blue Ridge region also be influenced by root-zone enrichment? We'll have a look at the results in the next article.

In summary, soil organic carbon is influenced by pedogenesis and management. We now have a way of determining how these factors can be separated. Results presented in Figure 1 indicate that grassland management on previous cropland could more than double the amount of carbon in the top foot of soil at one extreme, or it could increase

the amount of carbon by only 20% at another extreme. The root-zone enrichment calculation approach will be valuable for making more accurate estimations in the future of how various pasture management approaches influence soil carbon.

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1. According to the article, the parent material of many Piedmont soils is typically derived from

a. marine sand and clay deposits.

b. weathered bedrock known as saprolite.

c. recent alluvial sediments.

d. glacial till.

2. In the author's proposed approach for separating pedogenesis and management effects, soil organic carbon measured at an approximately 12-inch depth is used to represent

a. baseline soil carbon influenced primarily by soil-forming processes.

b. long-term carbon accumulation resulting from recent management practices.

c. carbon actively cycling within the crop rooting zone.

d. annual changes in soil carbon resulting from management decisions.

3. The article defines root-zone enrichment of soil organic carbon as

a. carbon stored below the primary rooting depth relative to surface soil carbon.
b. carbon accumulation in the root zone compared with carbon stocks in deeper subsoil layers.
c. carbon accumulated in the root zone beyond the amount expected from soil-forming factors alone.
d. carbon added to the soil profile through fertilizer, manure, and crop residue inputs.

4. What was the average root-zone enrichment of soil organic carbon reported for grassland systems in the study?

a. 4.8 tons/ac.
b. 8.3 tons/ac.
c. 13.1 tons/ac.
d. 39.6 tons/ac.

5. Based on the results presented in Figure 1, which statement is most accurate?

a. Conventional-till cropland stored more root-zone carbon than grassland in every soil group.
b. Baseline soil organic carbon was higher in cropland than grassland at every location.
c. Root-zone enrichment was directly proportional to total soil carbon stock.
d. Root-zone enrichment under grassland was greater than under

conventional-till cropland in each soil group.

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

Soil Carbon in the Carolinas series

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