



**Science
Societies**

Land use and forage management impacts on soil carbon

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What has the biggest impact on soil carbon in pasture systems: grazing, haying, or pasture age? Drawing on samples from 338 fields across North Carolina, this article reveals which management factors matter most for building soil carbon and why older pastures tend to accumulate carbon more rapidly over time.

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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Thanks for hanging in there with me through this series of articles on cattle and carbon! For some, the topic may be new and difficult, but for others, the information

might be familiar and derived logically from the natural order of the world in which we live. A progression from basic concepts to more difficult calculations and interpretations was intended. Therefore, you may be wondering what this is all about, and some confusion is ok when the information is new. However, it is my hope that some concepts and interpretations will be understandable and helpful along the way. If you have questions, perhaps others do too. Specific questions can be directed to me at alan.franzluebbers@usda.gov ([send message](#)). I will do my best to respond and provide clarifications.

This month's article puts emphasis on results obtained from a sampling of forage and grazing lands throughout North Carolina in 2023. The inception of this project was described in the [October 2026 issue](#). The sampling and its intent to obtain realistic estimates of soil carbon stocks on private lands in the U.S. was funded in part by the Foundation for Food and Agriculture with base support from the USDA Agricultural Research Service. It takes resources to conduct such research, and the focus on private lands will help to validate existing concepts and possibly develop new understanding of how conservation management using a variety of agroecological approaches can improve the resiliency of our food and fiber production systems.

Although it would be nearly impossible to sample even half of the fields on all 23,700 farms in North Carolina that have pastureland, I did sample 338 fields on 206 farms from December 2022 to March 2023. Sampling was at 0- to 4-, 4- to 12-, and 12- to 24-inch depth increments and two replicates were taken in each grassland field. Many different soil types and landscape features were sampled across 70 counties in North Carolina. From loamy sands in the Coastal Plain to silt loams in the Piedmont to clay loams in the Blue Ridge, a variety of soil textures provided a strong foundation to make a state-wide assessment.

Total stock of soil organic carbon is globally considered at the 0- to 12-inch depth. The portion of the total stock that is under management control has been characterized through the concept of root-zone enrichment. A unique baseline condition of each soil is derived from the soil carbon concentration at 12-inch depth using a mathematical approach.

Figure 1 illustrates results across North Carolina farms of the separation of baseline stock of carbon that is inherent in the soil type on your farm (a value that likely doesn't change in your lifetime) and root-zone enrichment that is controlled by the type of land use or management deployed over the past 10 to 50 years (longer legacy effects may be important too). Soils were sorted into a gradient of baseline soil carbon categories to show that the baseline stock can be different, but generally the effect of management on soil carbon is independent of the baseline stock.

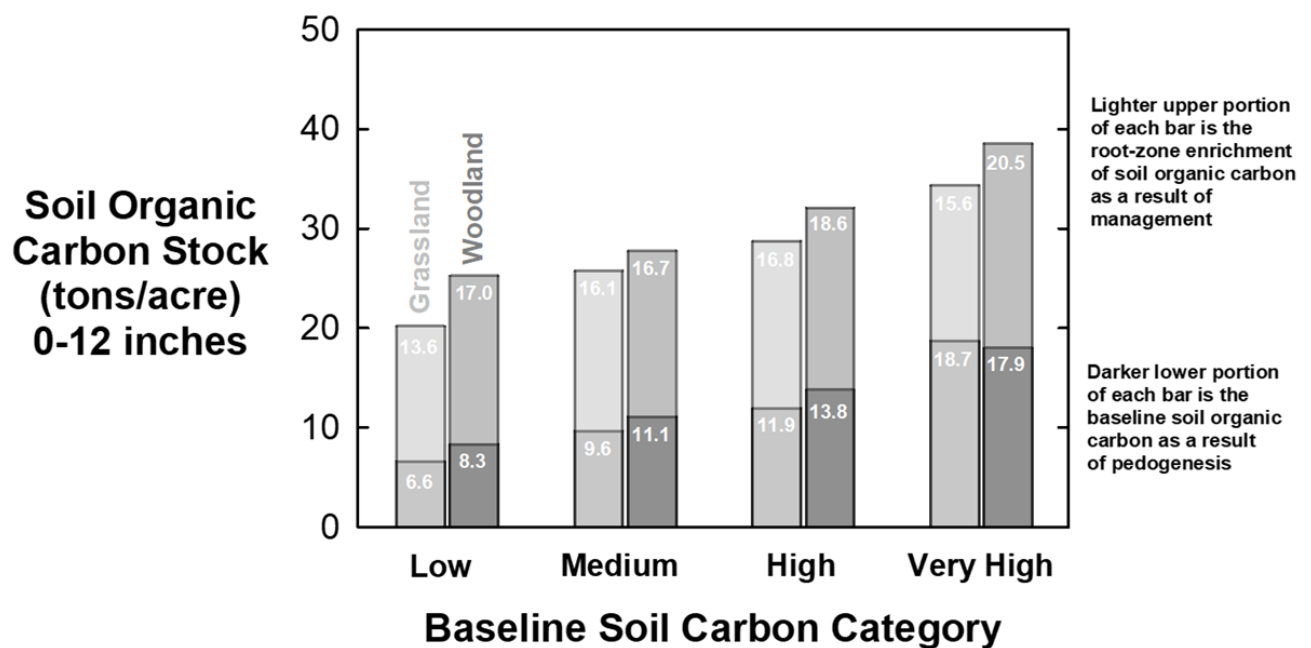


Figure 1. Average soil organic carbon stocks as affected by soil carbon category, source of formation, and land use.

In all baseline soil carbon categories, a similar absolute amount of carbon was stored in soil across the diversity of grassland management scenarios. A slightly greater level of soil carbon was being stored under woodland compared with grassland. However, the quality of that carbon may be different between these two broad land uses, and this will be explored in future articles.

Root-zone enrichment of soil organic carbon was greater under woodland than under grassland in each of the four soil groups. Farm woodlands are often completely undisturbed land uses, whereas cattle and tractors impact grasslands. On average, root-zone enrichment of soil organic carbon was 18.2 tons/ac under woodland and 15.5 tons/ac under grassland. That's an average difference of 2.7 tons/ac. You might recall from the January 2025 issue that root-zone enrichment under conventional-till cropland across North Carolina research stations was only 4.8 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 carbon category. 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 22.7 tons/ac in the low group, 26.7 tons/ac in the medium group, 30.4 tons/ac in the high group, and 36.4 tons/ac in the very high group.

From this sampling across North Carolina in 2023, many of the farmer collaborators completed a management history form. This information has been extremely useful to characterize the type of current and historical management for each field sampled. Although I'm hoping to get 65 more responses, a total of 273 fields have been characterized. A few contrasting management scenarios will be explored preliminary in the following.

As noted previously, total stock of soil organic carbon can be influenced by physiographic region due to soil formation factors. For this reason, I've repeated management contrasts within each of the regions in North Carolina, i.e. the Coastal Plain, Piedmont, and Blue Ridge.

Pastures that were grazed did not contain significantly different levels of soil carbon than those fields that were routinely hayed in any of the three regions (Table 1). There were more grazed fields sampled than hayed fields in all three regions. Hayed fields in the Blue Ridge region had the fewest observations (eight fields), and grazed pastures in the Piedmont had the greatest number of observations (110 fields).

Table 1. Average root-zone enrichment content and total stock of soil organic carbon under hayed and grazed fields in three physiographic regions of North Carolina.

Region	Root-zone enrichment of soil organic carbon (tons/acre)		Total stock of soil organic carbon (tons/acre)	
	Hayed	Grazed	Hayed	Grazed
Blue Ridge	15.3	16.1	32.9	32.6
Piedmont	16.3	16.6	26.7	27.2
Coastal	12.2	12.6	22.1	23.3

Plain
 Note: No statistically significant differences occurred between management pairs within a region.

For differences in root-zone enrichment to have been considered statistically significant would have required 1.3 tons/ac in the Blue Ridge (but the difference was only 0.8 tons/ac), 0.8 tons/ac in the Piedmont (but the difference was only 0.3 tons/ac) and 1.6 tons/ac in the Coastal Plain (but the difference was only 0.4 tons/ac).

Therefore, whether forage was mechanically harvested as hay or consumed directly by ruminant livestock did not significantly alter soil organic carbon accumulation in the primary root zone of the surface 12 inches.

Prolific rooting was likely occurring under both management styles, and those roots are considered large contributors to soil organic carbon accumulation. This lack of difference is mostly contrary to research–station results in the southeastern U.S., which typically indicates greater soil organic carbon under grazed than under hayed management.

Another management factor that could easily be discerned with more than a dozen observations per region and management category was that of pasture age (Table 2). Pasture age was a highly significant factor in each of the three regions. Young pastures had the lowest root–zone enrichment of soil organic carbon, and this result was logical based on time needed to allow soil organic carbon to accumulate under perennial pastures.

Table 2. Average root–zone enrichment contents of soil carbon under three different pasture age categories in three physiographic regions of North Carolina.

Region	Root–zone enrichment of soil organic carbon (tons/ac)				
	<10 years		10–25 years		>25 years
Blue Ridge	13.9	<<	16.0	=	16.5
Piedmont	14.8	<<	16.9	<	17.5
Coastal Plain	10.1	<<	12.4	<	14.3

Notes: Statistics highly significant differences probably between age categories within a region at the 90% level of confidence.

Accumulation of soil organic carbon was non-linear, meaning that the greatest accumulation rates per year were achieved early in pasture development and accumulation slowed to smaller increases over time. During the first 10 years, rates of soil organic carbon accumulation were 432 lb of C per acre per year in the Coastal Plain, 676 lb of C per acre per year in the Piedmont, and 1071 lb of C per acre per year in the Blue Ridge.

However, when calculated as the linear rate during a 50-year period, soil organic carbon accumulation was 219 lb of C per acre per year in the Coastal Plain, 209 lb of C per acre per year in the Piedmont, and 294 lb of C per acre per year in the Blue Ridge. These rates of soil organic carbon accumulation during a 50-year period are significant and slightly lower than values reported for [pasture-based livestock farms](#) in Virginia and in [tall-fescue-based pastures](#) across North Carolina and neighboring states, both of which averaged approximately 350 lb of C per acre per year.

Additional analyses of forage and grazing land management influences on soil organic carbon accumulation will be explored from this study. Some myths may be debunked, and some axioms could be verified. Validating science on working farms is needed to create better management systems so that others can learn from our experiences, but also to develop appropriate policies to foster proven practices and not just based on hunches.

Self-study CEU quiz

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1. In this study, what best describes "root-zone enrichment" of soil organic carbon?

- a. The total soil carbon stock measured to a 24-inch depth.
- b. The portion of soil carbon considered inherent to the soil type.
- c. The difference between woodland and grassland carbon stocks.
- d. The portion of soil carbon influenced by land use and management history.

2. Compared with grassland, woodland soils had

- a. lower root-zone enrichment in all soil carbon categories.
- b. slightly greater levels of stored soil carbon and greater root-zone enrichment.
- c. similar total soil carbon stocks but greater baseline carbon.
- d. greater total soil carbon only in the Blue Ridge region.

3. What was the average difference in root-zone enrichment between woodland and grassland across North Carolina?

- a. 0.8 tons/ac.
- b. 1.6 tons/ac.
- c. 2.7 tons/ac.

d. 4.8 tons/ac.

4. What effect did haying versus grazing have on soil organic carbon accumulation in the surface 12 inches?

- a. Grazed pastures consistently stored significantly more carbon than hayed fields.
- b. Hayed fields consistently stored significantly more carbon than grazed fields.
- c. Differences depended entirely on physiographic region.
- d. No statistically significant differences were detected within any region.

5. Which region had the highest estimated soil organic carbon accumulation rate during the first 10 years of pasture development?

- a. Coastal Plain.
- b. Piedmont.
- c. Blue Ridge.
- d. The rates were statistically equivalent among regions.

Appropriate as drafted with AI assistance and reviewed by the editorial team for accuracy and

Soil Carbon in the Carolinas series

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