NCASI Fact Sheet
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FS-24-02
APRIL 2024

Soil Carbon and Forest Management in the Northeastern US

Introduction

Soil is the foundation of forest ecosystems, including those in the northeastern US soil organic matter, for example, is mostly carbon and supports many ecosystem functions. Soil recycles nutrients critical for plant growth, is the base of a food web that supports biodiversity, and retains and releases water, protecting against erosion and improving water quality. Soil carbon is also important, as soils hold more carbon than the global atmosphere and all plants combined, thus making soils a critical component of the climate system. As carbon accounting and monitoring have become important parts of reporting initiatives and sustainability practices, forest stakeholders are increasingly focused on soils because of their carbon storage and ability to support forests' capacity to adapt to climate change and recover from disturbances. Collectively, these reasons make it important to understand how forest management affects soil carbon overall, and in geographic regions.

Soil Organic Matter: The Forest's Savings Account

In forest soils, organic matter is concentrated at the top of the soil profile (Fig. 1), where inputs of carbon-rich material such as dead roots, leaf litter, and microbial (fungal and bacterial) cells are continuously added to the soil. Most carbon added to the soil is destined to decompose, ultimately returning to the atmosphere as carbon dioxide. However, a fraction of this carbon persists in soils, over timescales ranging from decades to millennia. Soil carbon is measured by collecting samples, preparing and analyzing them in the laboratory according to widely accepted methods, and performing a few basic calculations to convert from the concentration of carbon in a sample (measured as a percentage) to the amount of carbon per area of ground (e.g., tons of carbon per acre). Additional measurements can reveal how long carbon has resided in different parts of the soil, where it originated, and how many nutrients it holds.

Considering the wide variety of carbon-rich plant, microbial, and animal tissues that become soil organic matter, the catch-all term "soil carbon" represents a practically infinite mixture of different chemical compounds. Despite this complexity, one unifying property of soil carbon is its tendency to act as a chemical "skeleton" to which other substances readily attach. Nitrogen, phosphorous, calcium, and many other elements crucial for plant and animal growth are intimately associated with carbon in soils. In this sense, soil carbon represents a long-term "savings account" for the forest, accumulating nutrients (and water) during times of excess and releasing them when supply is limited.

Typically, processes that add carbon to, or remove carbon from, soils are closely balanced, so a small change in either can tip the balance between soil carbon gains or losses. Maintaining soil carbon stocks helps mitigate climate change, support forest productivity, and increase resilience to disturbances. Because forest management can support these goals and ecosystem services and can directly tip the soil carbon balance, it is important to understand how different management practices may affect soil carbon. For example, prescribed fire, forest harvest, site preparation, reforestation, and fertilization can affect soil carbon through several processes: (1) alteration of soil physical properties (e.g., temperature or moisture), (2) addition of carbon to soil (e.g., harvest residues or charcoal), or (3) release of carbon from soils (e.g., decomposition or leaching). Considering these many interacting factors, forest management effects on soil carbon are highly variable, often appearing to be site-specific.

Figure 1. Forest soils in the northeastern U.S. often have large carbon stocks in their surface organic horizons and underlying mineral soils. The region's cool, wet climate and relatively coarse soil texture promotes water infiltration, which carries soluble plant- and litter-derived organic carbon downward through the profile and laterally along hillslopes. Baseline variation in soil carbon stocks is largely related to climate, topography, and soil texture and parent material in this region's often rocky soils.

Photo: Michael McHale

Forest Soil Carbon in Northeastern US

Soils and forests are diverse, as are the ecosystem services they provide. Thus, forest management strategies are necessarily diverse. Recent research shows that much of the variability in forest management effects on soil carbon is due to regional differences in climate, soil properties, and forest types. This diversity argues for a regional view of forest management and soil carbon. Aligning the scale of research with the scale at which forest management occurs can more precisely pinpoint management effects on soil carbon and improve stewardship across multiple spatial scales (e.g., stand, forest, landscape, region).

In the northeastern US, partial harvesting is the dominant forest management practice, compared to other regions of the US where prescribed fire, fuel reduction treatments, site preparation and replanting, soil amendments, or other practices are more common. Long-standing research and monitoring programs in the northeastern US have developed considerable data resources that have documented how land use change and forest management effects soil carbon.

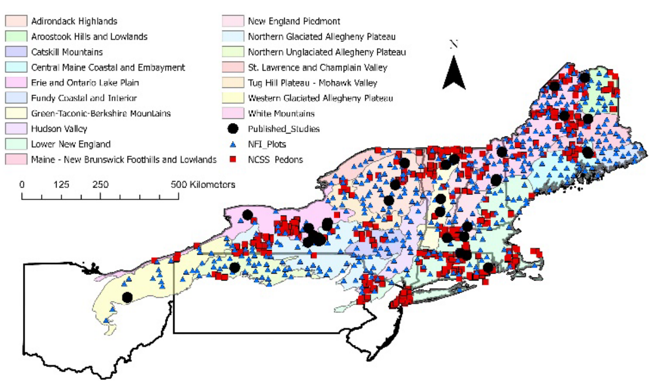

Figure 2. Ecoregions and soil carbon observations in the northeastern U.S. (Nave et al. 2024). *Click image to enlarge*

Land Use Change

Recent research has shown that land use change has significantly affected soil carbon stocks in the northeastern U.S. Long-term forest regrowth following deforestation from past agricultural clearing is currently driving soil carbon increases, at rates modulated by a range of factors, including forest type, soil parent material and texture, and the nature of past agricultural practices. However, after a century or more of net forest cover increase, forest cover in the northeastern US has begun to decline once again during the first decades of the 21st century. This deforestation trend, now driven more by urban development than agriculture, is decreasing soil carbon stocks at the regional level. In summary, whether for agriculture or development, deforestation decreases soil carbon; however, reforestation increases it.

Forest Harvesting

Unlike land use change, research has shown that forest harvesting does not affect soil carbon stocks in the northeastern U.S. A comprehensive review and synthesis of harvesting studies across the region has revealed no detectable effect of harvesting, and no place-based factors that drive exceptions to this general rule. While a small number of individual, site-level studies have detected significant changes (typically declines) in soil carbon stocks with forest harvest, these are highly exceptional and not related to any known driver. Existing research on the topic notably over-represents clearcutting, which comprises 60% of the literature on forest harvesting, yet represents only 21% of the area harvested in the northeastern U.S. over the past two to three decades. Further research on partial harvest systems, which are not sufficient to achieve all silvicultural goals but are much more common, may help develop a more nuanced understanding of forest harvest effects on soil carbon.

Management Guidelines

Forest harvesting in the northeastern U.S. is planned and implemented according to guidelines (and in some states, laws) to protect soil and water quality. Most of these guidelines and laws aim to protect physical aspects of water and soil quality (e.g., preventing sediment runoff to streams or avoiding soil compaction); none specifically address soil organic matter or carbon. Nonetheless, actions taken to protect soil and water quality likely impart soil carbon benefits, which may be especially important in settings where soil carbon may be more vulnerable to harvesting, such as steep slopes or boreal conifer wetlands. For example, restricting operations below a certain slope threshold or operating equipment on top of harvest residues mitigates physical damage to soils, and their carbon by association. However, as residue supply scales with harvest removals, and the available residues may be needed to meet other objectives (e.g., impeding browsing by white-tailed deer), implementing these and other soil-protecting guidelines will often involve carefully assessing co-benefits, tradeoffs, and priorities. Regardless, current forest management practices in the northeastern U.S. do not appear to have appreciable effects on soil carbon.

Reference

Nave L.E., DeLyser K.D., Domke G.M., Holub S.M., Janowiak M.K., Keller A.B., Peters M.P., Solarik K.A., Walters B.F., Swanston C.W. 2024. Land use change and forest management effects on soil carbon stocks in the Northeast U.S. *Carbon Balance and Management* 19:5. DOI: 10.1186/s13021-024-00251-7

For more information contact info@ncasi.org

This fact sheet summarizes research that is a product of the Northern Institute of Applied Climate Science, a collaborative partnership of Federal, forest sector, conservation, higher education, and tribal organizations led and supported in part by the U.S. Department of Agriculture, Forest Service. Funding was provided by NCASI and American Forests.