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Soil Carbon and Forest Management

Focus on the Great Lakes Region

Introduction

Soil is the foundation of forest ecosystems, and soil organic matter, which is mostly carbon, supports many ecosystem functions. It 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, both because of their carbon storage and because they support forests' capacity to adapt to climate change and recover from disturbances.

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. Scientists measure soil carbon 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.

The wide variety of carbon-rich plant, microbial, and animal tissues that becomes soil organic matter means that 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. In soils, nitrogen, phosphorous, calcium, and many other elements that are crucial for plant and animal growth are intimately associated with carbon. 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 slow climate change, support forest productivity, and increase resilience to disturbances. Because forest management can support these goals and ecosystem services, and can tip the soil carbon balance directly, it is important to understand how different management practices affect soil carbon. For example, prescribed fire, forest harvest, site preparation, reforestation, and fertilization can change soil carbon by altering: (1) soil physical properties (e.g., temperature or moisture), (2) carbon inputs to the soil (e.g., harvest residues or charcoal), or (3) processes that release 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: Dark colors indicate high carbon concentrations at the top of this forest soil profile. Climate, geology, forest type, and other factors affect how carbon enters, exits, and moves vertically and laterally within forest soils. Soil types differ in their properties and responses to disturbance, management, and other forces. Research and management that recognize these differences can provide place-based insights and practices that sustain soil carbon stocks while meeting other management goals.

Photo credit: Darwin Anderson soilsofcanada.ca

The Great Lakes Region

Introduction

Soils and forests are diverse, as are the ecosystem services they provide, and, thus, management strategies are necessarily diverse. Research shows that 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 on forest management and soil carbon. Aligning the scale of the research with the scale at which forest management occurs can more precisely pinpoint management effects on soil carbon and improve stewardship of this important resource.

Forestry and forest soil carbon are of great importance to the Lake States (Minnesota, Wisconsin, and Michigan), where the forest products industry employs more than 125,000 people and generates $60 billion annually. Comprising 6% of the conterminous US land area, the Lake States hold 9% of that area's forest soil carbon.

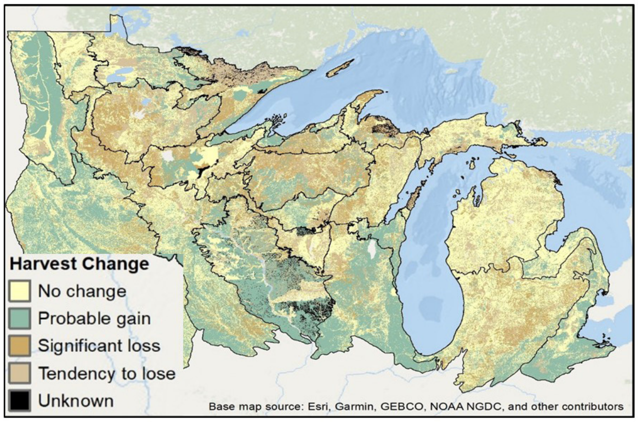

Figure 2: Probable harvest effects on soil carbon, mapped according to soil parent material and texture (Nave et al. 2021).

The Vulnerabilities

Recent research has shown that forest harvesting alters soil carbon across the Lake States, and potentially adjacent Canadian provinces as well, and these changes vary according to well-mapped soil properties, including parent material and texture. For example, soils formed in glacial outwash, which usually have medium to coarse textures, lose significant amounts of carbon from their surface horizons—exactly where carbon plays a crucial role in retaining water and nutrients in these often low-productivity soils. Planted pine stands are regionally extensive, especially on the poorest, coarsest, most acidic soils. There, they tend to have especially low soil carbon stocks, and thus are uniquely vulnerable to carbon loss. These soils have only begun to recover from past unsustainable harvesting and fires a century ago. Under modern practices, these planted pine stands can be managed effectively, provided their fragile soils are protected, such as by operating only when there is snow cover or frozen ground.

The Opportunities

Forest harvesting also creates opportunities for soil carbon gains. Research has revealed that fine-textured soils, especially in areas of once-extensive postglacial lakes, usually gain carbon in their surface horizons after harvest in the Lake States. Reforestation is another opportunity to increase soil carbon through management. For example, where mineral resource development has occurred and forests have not yet returned, planting trees dramatically increases soil carbon, compared to the potential delay associated with natural regeneration.

Management Guidelines

Nearly all forest harvesting in the Lake States is planned according to guidelines to protect soil and water quality, which have been developed by government agencies, non-governmental organizations, and third-party certification programs. Almost all of these guidelines include activities to protect soils. However, none specifically addresses soil carbon. Nonetheless, following soil-protecting guidelines will most likely provide notable soil carbon benefits. For example, operating equipment on top of harvest residues protects soil structure from physical damage, thus protecting structurally-stabilized soil carbon. This form of soil carbon, recognizable in the field as aggregates ("crumbs" of closely bound soil particles and organic matter), is important for soil productivity on both outwash soils where losses are likely, and on fine-textured lake plain soils where gains are probable. Other guidelines, such as residue management, may have more nuanced effects on soil carbon. For example, where harvest residues are retained due to soil nutrient or productivity concerns—often on outwash soils—it may be beneficial for processor operators to position the residues over areas of exposed soil as they work. In addition to preventing soil erosion and protecting water quality, covering exposed soils with harvest residues can help protect soil carbon stocks, because shading the soil reduces heating and decomposition. Not only do such practices keep carbon in soils out of the atmosphere, they support management goals and ecosystem functions such as regeneration and future forest productivity.

Reference

Nave, L., DeLyser, K., Domke, G., Janowiak, M., Ontl, T., Sprague, E., Walters, B., and Swanston, C. 2021. Land use and management effects on soil carbon in U.S. Lake States, with emphasis on forestry, fire, and reforestation. *Ecological Applications* 31(6):e02356. https://doi.org/10.1002/eap.2356

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