

# Monitoring Soil Carbon Stocks in Tropical Forests: Integrating Traditional Methods and Remote Sensing for Climate Action

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# DESCRIPTION

Soil Organic Carbon (SOC) plays a pivotal role in regulating global carbon cycles and sustaining soil health, particularly in ecologically rich regions such as tropical forests. These forests, located primarily between the Tropic of Cancer and Tropic of Capricorn, are not only biodiversity hotspots but also critical carbon sinks. Accurately estimating SOC stocks and understanding the impacts influencing them is fundamental for climate change mitigation, sustainable land use, and environmental conservation.

## Importance of SOC in tropical forests

Tropical forests store a significant portion of the Earth's terrestrial carbon, with soils accounting for a large share-often more than the vegetation above ground. SOC serves as a major reservoir, influencing carbon sequestration potential and playing a critical role in nutrient cycling, water retention, and soil structure. These forests experience high biomass productivity and decomposition rates, which contribute to dynamic and complex SOC fluxes.

Estimating SOC in tropical forest soils, however, is challenging due to the heterogeneity of landscapes, variable rainfall patterns, vegetation diversity, and complex soil compositions. Additionally, human-induced activities such as deforestation, agricultural expansion, and mining have made these ecosystems increasingly vulnerable, altering natural SOC dynamics.

#### Methods of estimating SOC

The estimation of SOC typically involves direct sampling and laboratory analyses. Soil samples are collected at various depths, and SOC content is determined using techniques like dry combustion (via elemental analyzers) or wet oxidation methods (Walkley-Black method). These methods, though reliable, are labor-intensive and may not capture spatial variability effectively.

To overcome these limitations, remote sensing and geospatial techniques are increasingly employed. Satellite imagery, LiDAR,

and UAV-based sensors combined with Digital Soil Mapping (DSM) approaches provide scalable, cost-effective, and nondestructive means of estimating SOC across large forested regions. Machine learning algorithms also offer promise by integrating multiple datasets-topography, vegetation indices, land cover, and climate data-to model SOC distribution.

However, these methods are not without challenges. Remote sensing-derived SOC estimates require calibration with groundtruth data, and predictive models may be limited by data availability or transferability across regions. There is a need for standardized methodologies and region-specific models to ensure accuracy and comparability.

#### Impacts on SOC in tropical forests

SOC in tropical forests is affected by both natural and anthropogenic factors. Among the major drivers are:

**Deforestation and land use change**: The conversion of forests into croplands, pastures, or urban areas leads to substantial SOC losses. Tree removal disrupts litter input, microbial activity, and root biomass-all crucial contributors to SOC. Studies suggest that up to 50% of SOC can be lost within decades of deforestation.

**Climate change:** Rising temperatures and altered precipitation patterns impact decomposition rates and microbial activity. While higher temperatures can increase decomposition and CO2 release from soils, extreme rainfall events may result in leaching and erosion of carbon-rich topsoils.

**Fire and biomass burning:** Forest fires, both natural and anthropogenic, release significant amounts of stored carbon into the atmosphere and reduce SOC by combusting surface organic layers. Repeated burning depletes soil fertility and alters long-term carbon balance.

Agroforestry and reforestation practices: On a positive note, reforestation, afforestation, and sustainable agroforestry systems can restore SOC levels by increasing organic inputs and

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stabilizing soil structure. Incorporating leguminous species and cover crops in degraded lands enhances SOC sequestration.

## Policy implications and future directions

SOC management in tropical forests must be prioritized in climate mitigation strategies. Programs such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) hinge on accurate carbon accounting, making robust SOC estimation methodologies essential. Furthermore, including SOC in national greenhouse gas inventories and carbon credit systems can incentivize conservation and sustainable land use.

# CONCLUSION

To improve SOC monitoring, a combination of high-resolution spatial data, ground-based measurements, and local ecological

knowledge is essential. Cross-disciplinary collaboration-among soil scientists, ecologists, data scientists, and policy makers is vital to develop integrative and adaptive SOC monitoring frameworks. Tropical forests are central to the Earth's carbon dynamics, and their soils hold immense, often underestimated, carbon reservoirs. Advancements in SOC estimation technologies, coupled with effective conservation and restoration strategies, offer a pathway to mitigate climate change impacts, enhance ecosystem resilience, and ensure sustainable land management. Continuous investment in research, technology, and community engagement is key to unlocking the full potential of soil as a climate ally.