CHANGE DETECTION FOR SOIL CARBON IN THE FOREST INVENTORY AND ANALYSIS

An-Min Wu, Edward A. Nater, Charles H. Perry, Brent J. Dalzell, and Barry T. Wilson

Abstract—Estimates of carbon stocks and stock changes in the U.S. Department of Agriculture Forest Service’s Forest Inventory and Analysis (FIA) Program are reported as the official United States submission to the UN Framework Convention on Climate Change. Soil, as a critical component of the forest carbon stocks, has been sampled in about 10-year intervals in FIA with the re-measurement underway. However, the magnitude of detectable change in soil organic carbon (SOC) with the current sampling scheme is unknown. We aim to identify SOC variability and to best determine minimum detectable changes in SOC under the current sampling scheme. The project seeks to: identify statistical relationships between SOC and environmental covariates; normalize SOC data for main forest-type groups (FTGs) using identified covariates; and determine the minimum detectable change in the normalized SOC using power analysis. We investigated SOC variability for 8 FTGs: Oak-Hickory, Maple-Beech-Birch, Pinyon-Juniper, Loblolly-Shortleaf Pine, Aspen-Birch, Douglas-Fir, Fir-Spruce-Mountain Hemlock and Woodland Hardwoods. Relationships between SOC and environmental covariates (biomass/soil properties in FIA, PRISM climate data, and DEM-derived terrain attributes) are determined by multiple linear regression and are used to normalize SOC variability. The results showed that terrain attributes were not significant in explaining SOC in the FIA dataset and climate data were only significant in certain FTGs locations. Except for Oak-Hickory, Maple-Beech-Birch and Pinyon-Juniper groups, sample numbers are insufficient to detect a change in SOC less than 10 percent (%) of the mean. To guide future sampling efforts, we will continue our study on detecting minimal change in SOC and to explore sample number and sampling frequency scenarios to inform future soil sampling protocols.

The U.S. Department of Agriculture Forest Service’s Forest Inventory and Analysis (FIA) Program assesses nationwide forest resources to ensure sustainable management and to report critical status and trends (Smith, 2002). One of the critical reports from the FIA is an estimate of forest carbon stocks in biomass and soil as a part of the official United States submission to the United Nations Framework Convention on Climate Change (Smith et al., 2013). Although soil is the critical component in the forest carbon system, the magnitude of detectable change in soil organic carbon (SOC) in FIA is still unknown for current sampling density and time intervals (soils are sampled at roughly 10-yr or longer intervals; Woodall et al., 2010). In order to ensure wise investment on sampling efforts, it is essential to determine which levels of SOC change are statistically meaningful.

In this study, our goals are to identify SOC variability in FIA and to determine the minimum SOC change that can be detected. Our specific objectives are to 1) identify relationships between SOC and environmental covariates, 2) reduce environment-affected SOC variability by data normalization, and 3) determine detectable SOC change using power analysis.

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MATERIALS

Mineral soils in FIA are sampled in 0-10cm and 10-20cm depth intervals and in a 10-year or longer time interval. The current FIA database, measured between 1999–2011, contains 2783 unique plot samples with SOC measurements available in both depths. We used the latest sampling data from sites in the conterminous US; 5 coastal sites lacking elevation coverage in our terrain model were eliminated. A total of 2763 samples were used for the analysis.

We applied the resampled 250-m Elevation Derivatives for National Applications(EDNA) for terrain attributes and the 800-m long-term climate norms from the PRISM data for climate parameters.

METHODS

We calculated composite SOC density in the top 20 cm of soil and investigated its variability within forest-type groups (FTGs) at the sampling sites. Statistical analyses were stratified by FTGs to reduce variability in environmental and management conditions. FTGs selected for analyses were Oak-Hickory, Maple-Beech-Birch, Pinyon-Juniper, Loblolly-Shortleaf Pine, Aspen-Birch, Douglas-Fir, Fir-Spruce-Mountain Hemlock and Woodland Hardwoods.

We used multiple linear regression to build a best-fit SOC model for each FTG using readily available environmental covariates such as topographic attributes, climate variables, and biomass and soil properties. Forest biomass C pools (e.g., understory aboveground & belowground, dead, standing dead, and litter; litter and forest floor thickness) and soil properties (ECEC, pH, total water, total N, coarse fragments, and texture layers) are available in the FIA database. We derived topographic attributes, including elevation, slope, aspect, plan/profile curvature, and contributing area, from the EDNA dataset. We obtained 30-year averaged annual precipitation and temperature (minimum, mean, and maximum) estimates from PRISM. Environmental covariates in best-fit regression models were selected for data normalization.

To make SOC comparable across various environmental conditions in the US, we normalized the distribution to the means of the identified covariates before SOC change detection. We adjusted SOC density by off-setting the distance of covariate values to the means of the covariates with proportions using the partial regression coefficients of the SOC model. Mean, standard deviation, and coefficient of variation (CV) of SOC density in each FTG before and after data normalization were examined.

We then ran power analysis to determine the minimum detectable change in SOC using current sample numbers. We calculated the required sample sizes needed to detect specific levels of change. Power analysis provides the perspectives of statistical significance (Cohen, 1969). Its 4 components – sample size (n), effect size (Cohen’s d), a significance level (Type I error, or α) and power (=1-Type II error) – allow us to determine the sample size required or an experimental effect when giving constraints to the other components. We defaulted the significance level to be 0.05 with a power of 0.8 to estimate the required sample size for a given effect, or vice versa.

RESULTS: SOC RELATIONSHIPS

Overall, SOC variability across all sites is high. SOC density for all sites has a mean of 5.08 kg m⁻² with a coefficient of variation (CV) of 0.64. The SOC distribution varies by FTGs. The means of SOC range from 3.18 kg m⁻² for the Loblolly-Shortleaf pine group to 6.97 kg m⁻² for the Maple-Beech-Birch group (Table 1).

Preliminary analyses showed no significant relationships between SOC and terrain attributes, and only a few FTGs displayed significant relationships with climate. SOC models are mainly associated with biomass and soil properties (e.g. litter thickness or carbon, ECEC, coarse fragments). Besides these properties, SOC in Woodland Hardwoods, Pinyon-Juniper, and Oak-Hickory groups is also driven by precipitation and/or temperature.
RESULTS: DATA NORMALIZATION
Based on relationships between SOC and covariates identified in SOC models, data normalization reduces SOC variability for all FTGs. Data normalization adjusted diverse site environments to the means of covariates and improved CV by from 14 to 49.8 percent (%), depending on FTGs (Table 1).

RESULTS: POWER ANALYSIS
Comparing SOC detectable changes before and after normalization, the effect sizes for all FTGs increase with data normalization. Hence, the number of samples required for detecting change in SOC decreases. For example, Oak-Hickory (n=584), Maple-Beech-Birch (n=292) and Pinyon-Juniper (n=279) groups have sufficient sampling sites to detect SOC change ≤10 percent (%) of the mean, but other FTGs require more samples for such detection (Table 1). The Douglas-fir group, which currently has 174 sample sites, would need 406 samples to detect a 10 percent (%) change.

DISCUSSION
Terrain attributes were surprisingly not significant in building SOC models. Terrain attributes are typically a strong driver in SOC formation (Wu, 2014), but our results suggest that topography is not a major factor in driving SOC in forests at the national extent, possibly due to regional variations in ecological processes or terrain data resolution (Cao et al., 2012, Minasny et al., 2013). Soil properties used to build SOC models are soil texture, particle size and related properties (e.g. ECEC, coarse fragments, and total water), suggesting texture as an important factor to further investigate C stocks and stock changes. Future sampling effort might also focus in collecting more detailed soil texture information.

Using covariate relationships, data normalization reduces sample numbers required in a given effect size. Data normalization, therefore, is effective for planning sampling efforts when study sites are located across a large area with diverse environmental conditions.

Except for Oak-Hickory, Maple-Beech-Birch and Pinyon-Juniper groups, current FIA sample numbers are insufficient to detect changes in SOC stocks ≤10 percent (%) of the mean. While re-measurements may allow us to detect SOC stock changes, our ability to do so is limited by the current number of sampling sites for most FTGs.

ACKNOWLEDGMENT
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<table>
<thead>
<tr>
<th>Forest-type groups</th>
<th>n</th>
<th>SOC density, 0-20 cm (kg m⁻²)</th>
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<td></td>
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Abbreviations are as follows: SOC = soil organic carbon, SD = standard deviation, CV = coefficient of variation.
LITERATURE CITED


