

EXTRAPOLATING EXISTING SOIL ORGANIC CARBON DATA TO ESTIMATE SOIL ORGANIC CARBON STOCKS BELOW 20 CM

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Abstract—Estimates of forest soil organic carbon stocks across the US are currently developed from expert opinion in STATSGO/SSURGO and linked to forest type. The results are reported to the US EPA as the official United States submission to the UN Framework Convention on Climate Change. Beginning in 2015, however, estimates of soil organic carbon (SOC) stocks will be based on SOC data from soil cores collected in the field (0-10 and 10-20 cm depth). In addition, the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance suggests these estimates extend to at least 30 cm for all forested lands. This study reports the results of that extrapolation effort. Data for this effort were obtained from the International Soil Carbon Network (ISCN) database, from analyses of more than 500 150 cm deep cores collected from forested sites across the Upper Midwest, and from cores taken at several US Forest Service Experimental Forests. SOC contents were adjusted to 0-10, 10-20, and 20-50 cm depth increments by a weighted average estimation technique if needed. Multiple linear regression modeling was used to predict the percent SOC of the 20 to 50 cm depth layer from the percent SOC of the 0-10 and 10-20 cm depth layers. Additional covariates included climatic data, latitude and longitude. Preliminary analyses show a best fit prediction $R^2 > 0.6$ for all data.

INTRODUCTION

The Forest Inventory Analysis (FIA) program has established a systematic measurement approach to provide statistically valid measures of a wide array of forest parameters, such as aboveground living tree biomass, dead and down biomass, woody shrub biomass, and others at thousands of forested sites across the United States. Soils are sampled at 0-10 and 10-20 cm depths at a subset (1 of 16) of sites and analyzed for soil organic carbon, pH, extractable metals, and other properties.

Currently, estimates of forest soil organic carbon (SOC) stocks across the US are developed from expert opinion in STATSGO/SSURGO and linked to forest type. Results

are reported to the US EPA as the official US submission to the UN Framework Convention on Climate Change. Starting in 2015, however, estimates of SOC stocks will be based on SOC data from soil cores (0-10 and 10-20 cm depth) collected in the field by FIA. In addition, the IPCC Good Practice Guidance suggests these estimates extend to at least 30 cm for all forested lands.

Because FIA has not collected soils data below 20 cm, the SOC content of these deeper horizons must be estimated by statistical modeling. Further, this pedometric model can only utilize data currently in the FIA database and environmental data that can be readily obtained from other established sources.

Our objectives are to 1) develop predictive statistical relationships for deep (20-50 cm) percent SOC from percent SOC in the 0-10 and 10-20 cm depth increments and from environmental variables that can be estimated for forested sites across the US; and 2) combine these new percent SOC estimates with bulk density data to estimate SOC stocks for soils below 20 cm.

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MATERIALS AND METHODS

Mineral soil SOC data for US forests were obtained from three sources: 1) the International Soil Carbon Network (ISCN) database (International Soil Carbon Network, 2012), 2) a study we (Nater and Fissore) conducted where more than 500 deep (150cm) cores were collected from forested sites in Minnesota, Michigan, and Wisconsin, and 3) data from deep soil cores collected on several USFS Experimental Forests. Because the cores in the ISCN and the Experimental Forests were collected by multiple investigators using different protocols, sample depth increments varied widely. In order to make this model applicable to existing FIA soils data, we had to standardize the data to 0-10 and 10-20 cm depth increments as per FIA protocols, and the 20-50 cm depth increment we sought to model. We estimated the percent SOC of the three depth increments by a weighted average method. The datasets were carefully examined before and after production of the estimate to eliminate cores <50 cm deep, cores having missing SOC values, or cores that had SOC values > 12 percent (generally indicating forest floor or an organic soil horizon) or ≤ 0 percent. The initial combined dataset had 3,700 cores; more than 2800 remained after data validation.

All cores had geospatial (latitude and longitude) data, which allowed us to obtain environmental data that could be used as covariates in our regression modeling. We obtained 30-year annual precipitation, minimum temperature, mean temperature, and maximum temperature for all sites (excluding sites in Alaska, Hawaii, and Puerto Rico, where estimates are unavailable) from PRISM (PRISM Climate Group, 2015).

Stepwise multiple regression analyses were conducted in the statistical package R, v. 0.98.953 (R Development Core Team, 2011)

RESULTS

Not surprisingly, percent SOC values were not normally distributed and were normalized by a log transform. The dependent variable, $\text{Log}(\text{PercentC})_{35}$, is the log of the percent SOC in the 20-50 cm depth increment (35 cm is the midpoint of the increment). Independent variables used in the regression modeling included:

- $\text{Log}(\text{PercentC})_5$ = log of PercentC in the 0-10 cm depth increment,
- $\text{Log}(\text{PercentC})_{15}$ = log of PercentC in the 10-20 cm depth increment,
- Precip = the 30-year average precipitation (mm) obtained from PRISM,
- Tmin = the minimum temperature (C) obtained from PRISM,
- Lat = latitude in degrees, and
- Long = longitude in degrees.

Stepwise multiple regression modeling to predict $\text{Log}(\text{PercentC})_{35}$ for the entire US produced the following model:

$$\begin{aligned}\text{Log}(\text{PercentC})_{35} = & -0.636 + 0.679*\text{Log}(\text{PercentC})_{15} \\ & -0.0039*\text{Long} + 0.103*\text{Log}(\text{PercentC})_5 - \\ & 0.0086*\text{Tmin} + 0.000064*\text{Precip} = 0.0029*\text{Lat}\end{aligned}$$

Adjusted $R^2 = 0.63$, $df = 2817$, $F = 809.3$, and $p < 2.2e-16$. With the exception of latitude, all variables in the regression were significant to $p < 0.001$.

The strong relationship observed with longitude suggested that a better fit might be obtained by regionalizing the dataset and separately analyzing individual regions. We split the dataset into three regions based on longitude: an Eastern Region (longitude > -105°, which is roughly in central Nebraska), a Western Region (longitude < -105° and > -128°), and a Far West Region (longitude < 128°, that only included Alaska and Hawaii). Because PRISM climate data are not available for Alaska or Hawaii, they would be removed from any analysis using Precip or Tmin; consequently, we felt it best to put them in their own, albeit small, region.

Individual analyses of the three regions follows:

Eastern Region

The best fit model for the Eastern Region was:

$$\text{Log(PercentC)}_{35} = -0.364 + 0.609 * \text{Log(PercentC)}_{15} + 0.119 * \text{Log(PercentC)}_5 - 0.006 * \text{Tmin}$$

Adjusted $R^2 = 0.49$, $df = 1971$, $F = 834.6$, and $p < 2.2e-16$. All variables in the regression were significant to $p < 0.001$.

Western Region

The best fit model for the Western Region was:

$$\text{Log(PercentC)}_{35} = -0.00312 + 0.855 * \text{Log(PercentC)}_{15} + 0.000047 * \text{Precip} - 0.006 * \text{Lat}$$

Adjusted $R^2 = 0.74$, $df = 846$, $F = 825$, and $p < 2.2e-16$. All variables in the regression were significant to $p < 0.001$.

Far West Region

The best fit model for the Far West Region was:

$$\text{Log(PercentC)}_{35} = -0.00312 + 0.855 * \text{Log(PercentC)}_{15}$$

Adjusted $R^2 = 0.79$, $df = 40$, $F = 156.7$, and $p = 2.05e-15$. $\text{Log(PercentC)}_{15}$ was significant to $p < 0.001$; no other variables were significant.

DISCUSSION

Overall, the regression models provide a good estimate of the percent SOC in the 20-50 cm depth increment. This is particularly true in the Western Region, less so in the Eastern Region. This east-west disparity may be due to a longer history of forest soil disturbance in the eastern US, which could alter these relationships, or it may be due to the higher occurrence of poorly drained soils in the east, which tend to have much higher SOC contents than well-drained soils. Improvements to the model fit may be possible with the inclusion of soil textural data (estimated from NRCS Soil Survey data) and/or elevation data.

Estimates of soil bulk density will be required in order to calculate SOC stocks at depth. FIA has no bulk density data for depths below 20 cm; therefore these data will have to be estimated, most likely from the USDA NRCS Soil Survey database for locations where data are present, and from other pedometric models for other locations (Sequeira et al. 2014).

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