Current organic carbon stock in topsoil of forest land in Japan

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Abstract
To evaluate the current organic carbon stock in forest topsoil in Japan, a systematic survey has been carried out since 2006. As of the end of 2008, organic carbon densities in the first 0.3 m of soil had been measured at 1,200 forest sites. Organic carbon density ranged from 0.34 to 19.51 kg/m^2 for mineral soils. The combination of wide variation in temperate conditions reflected by mean annual temperature, the unstableness of soil material implied by slope angles, and the widespread distribution of volcanic ejecta are supposed to create the complicated distribution of soil organic carbon stock in Japanese forests. The mean organic carbon density was 7.05 ± 3.03 kg/m^2 (mean ± SD) for all samples including organic soil. This value is lower than a previous estimate, possibly due to differences in the method of estimating the coarse fragment volume in the soil mass and the method of dry bulk density measurement.

Key Words
Forest soil, Japan, organic carbon stock, systematic sampling.

Introduction

A strategic survey to obtain a soil carbon inventory of Japan's forest sector and evaluate the current soil carbon stock was launched in 2006. The goal was to obtain a comprehensive survey of all forestlands in Japan over 5 years, from 2006 to 2011 (Takahashi and Morisada 2008). The layout of the survey sites and soil sampling method were established considering the effect of soil variability on organic carbon stock evaluation, as soil variability can cause wide differences in estimations of soil carbon stock (Swift 2001). To avoid sample bias, survey sites were systematically selected from the plots of the Forest Resources Monitoring Survey conducted by the Forestry Agency, Government of Japan (Takahashi and Morisada 2008). The Monitoring Survey plots were set up at 4 × 4-km grid intervals to cover the whole forested area of Japan, and every fifth plot was designated as a special plot (Hirata *et al.* 2009). The survey sites for the current project correspond to the special plots of the Monitoring Survey and represent one-fifth of the Monitoring Survey plots. The current project will survey approximately 3,000 sites located about every 80 km^2 throughout the forestland of Japan. The project is expected to advance understanding of soil variability at the national scale. Systematic soil sampling has been performed to avoid sampling bias (Takahashi and Morisada 2008). By the end of 2008, measurement of organic carbon densities in topsoil had been completed at half of the planned survey sites. The surveyed sites appear to evenly cover forested land, and the results obtained to date can offer insight into the distribution of organic carbon stocks in forest soils in Japan. In this paper, we present interim results from the first 3 years of the survey.

Methods

Measurement of soil organic carbon density

Briefly, the field sampling method (Forest Sinks Working Group 2007a) was as follows. Soil was sampled at four systematically designated points at a Monitoring Survey plot. The depth interval of sampling was fixed to 0.3 m. Soil samples for carbon content measurement were taken from soil depths of 0–0.05, 0.05–0.10, and 0.15–0.30 m after collecting litter samples from the soil surface. Undisturbed soil samples for bulk density measurement were taken from the same depth intervals using a 400-mL soil-sampling cylinder (100 cm^2 × 4 cm). In the case that a cylinder could not be used, an excavating method was applied. The volume ratio of coarse fragments (>2 mm) was estimated by eye using a chart (Oyama and Takehara 1967) for comparison.

The methods of sample analysis (Forest Sinks Working Group 2007b) and calculation of soil organic carbon density in each plot were as follows.
The bulk density of fine earth (BD) was calculated by
$BD = (Sw – Gw – Rw) / V$,
where Sw is the oven-dry weight of the sample, Gw is oven-dry weight of coarse fragments in the sample,

Rw is oven-dry weight of roots in the sample, and V is the sample volume.
The carbon concentration of fine earth was determined by a dry combustion method.
The soil organic carbon density for a sampling point (SOC, C kg/m^2) was estimated as
$SOC = \Sigma\ OC_i \times BD_i \times D_i \times (1 - S_i)$,
where OC_i is the concentration of organic carbon in layer i, BD_i is the bulk density of layer i, D_i is the thickness of layer i, and S_i is the volume ratio of coarse fragments in layer i. The mean density of sampling points in the plot was used as the representative value of soil organic carbon density in each plot.

Examination of the distribution of organic carbon stocks
Correlations of organic carbon density by plot with the temperature condition, slope condition, and parent material were examined considering major characteristics of the pedogenesis of Japanese soils (Kyuma 1990). Mean annual temperature estimated from digital climate data (Japan Meteorological Agency 2002) represented the temperature condition of a plot. The slope condition was given by slope data for each plot derived from the site description of the Monitoring Survey report (Forestry Agency unpublished). The surface geology estimated from digital geology data (Wakamatsu *et al.* 2005) was used to identify the parent material. Data from 1,203 sites at which the soil organic carbon density was plotted in three or four of the four sampling points were used for this study.

Results
The soil organic carbon density of plots ranged from 0.34 to 19.51 kg/m^2 for mineral soils. The organic carbon density of organic soil was 25.0 kg/m^2 (n = 1). Regional differences were found in the distribution of organic carbon density. In general, the organic carbon density of forest topsoil was high in the eastern region and low in the western region. This regional difference in carbon density corresponded to the relationship between carbon density and the temperature condition. Soil carbon density tended to increase with the decrease in mean annual temperature, but the correlation between carbon density and mean annual temperature was not strong (Figure 1). Soil carbon density tended to be low in steeply sloped areas (Figure 2). Considering the influence of slope will provide better evaluations of the organic carbon stock in Japanese forestland because about 30% of forests are located on slopes steeper than 30 degrees (Forestry Agency 1968). The carbon density also differed according to the geologic age of the land surface (Figure 3). The widely distributed volcanic ejecta in Japan clearly influence the organic carbon stock in topsoil. However, given the present limited knowledge of the areal and depth extent of volcanic ejecta, it is difficult to distinguish the influence of volcanic ejecta on organic carbon stock at the nationwide scale.

The combination of wide variation in temperate conditions shown by mean annual temperature, the unstableness of soil material implied by slope degrees, and the wide distribution of volcanic ejecta are supposed to create the complicated distribution of soil organic carbon stock in Japan's forests.
The present organic carbon density was estimated to be 7.05 ± 3.03 kg/m^2 (mean ± SD) for all samples including organic soil. This estimate is lower than a previous estimate by Morisada *et al.* (2004). The difference between the two estimates may be attributable to differences in the method of estimating the volume of coarse fragments. Volume of coarse fragments was estimated in the field for the present survey, but volume of coarse fragments in the previous estimate was estimated from the abundance of stone in field descriptions (Morisada *et al.* 2004). Differences in the method of dry bulk density measurement may also have contributed to the difference between the estimates. Sampling strategy also might effect on the estimation of soil organic carbon stock. Systematic sampling was performed in the present survey, whereas samples in the previous estimate were judgement sampling (Petersen and Calvin 1965).

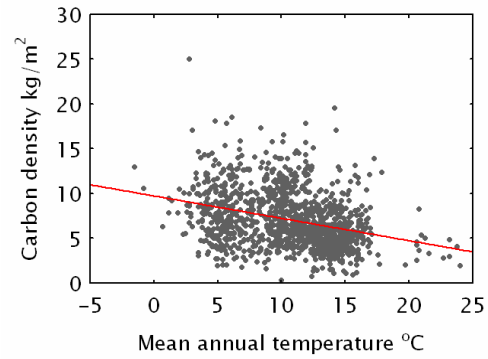

Figure 1. Relationship between mean annual temperature and organic carbon density.

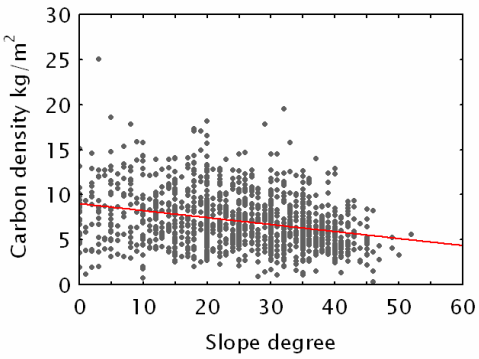

Figure 2. Relationship between slope degree and organic carbon density.

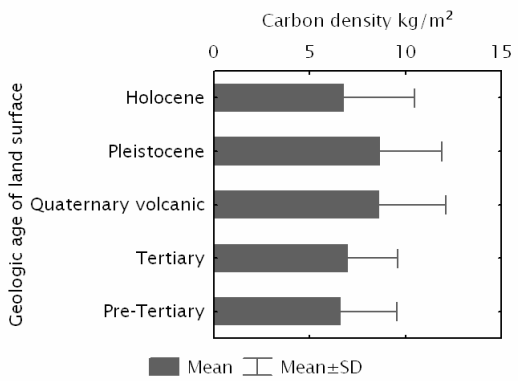

Figure 3. Carbon density by the geological conditions of the plots.

Conclusion

The present organic carbon stock in forest topsoil in Japan was estimated from the results of a systematic soil survey. Wide variation in temperature, unstable soil materials, and widespread distribution of volcanic ejecta are supposed to create the complicated distribution of soil organic carbon stock in Japanese forests.

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