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Dynamics of soil carbon in a beechwood chronosequence forest

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Abstract

Accurate estimates of forest soil organic matter (OM) are now crucial to predictions of global C cycling. This work addresses soil C stocks and dynamics throughout a managed beechwood chronosequence (28–197 years old, Normandy, France). Throughout this rotation, we investigated the variation patterns of (i) C stocks in soil and humic epipedon, (ii) macro-morphological characteristics of humic epipedon, and (iii) mass, C content and C-to-N ratio in physical fractions of humic epipedon. The fractions isolated were large debris (>2000 μm), coarse particular OM (cPOM, 200–2000 μm), fine particular OM (fPOM, 50–200 μm) and the mineral associated OM (MaOM, <50 μm).

Soil C stocks remained unchanged between silvicultural phases, indicating a weak impact of this even-aged forest rotation on soil C sequestration. While humic epipedon mass and depth only slightly varied with beech development, C stocks in the holorganic layers were modified and the use of physical fractionation allowed us to discuss different aspect of quantitative and qualitative changes that occurred throughout the silvicultural rotation. Hence, changes in humic epipedon composition may be attributed to the modification of beech life-history traits with its maturation (growth vs. reproduction). Our results showed that C-POM can reached very high values (68%) in organo-mineral layers of older managed forest and that C-MaOM did not significantly change revealing the resistance of humified fractions of humic epipedon to logging and regeneration practices. C-to-N results indicated that N was probably not a limiting factor to litter degradation and explained our findings that OM did not accumulate in O horizons.

This work confirms that forest harvesting and regeneration practices may have few effects on soil and humic epipedon C stocks, and that short- and long-term effects can be complex and may imply mechanisms with opposite effects.

Keywords: 200-years forest rotation; Silvicultural phases; Soil organic matter fractions; Soil organic matter reserves; Acidic soil

1. Introduction

With the focus on the increasing levels of atmospheric CO_2 and the potential for global climate change, there is an urgent need to assess the feasibility of managing ecosystems to store carbon. The articles 3.3 and 3.4 of the Kyoto Protocol request industrialised countries to estimate with transparent and verifiable methods the amount of C stored in ecosystems in different pools (Annex B countries) and its temporal dynamics. Forests play a major role in the global C cycle (Hagedorn et al., 2001). Carbon stored in forest ecosystems represents a substantial part of the global C stock. Worldwide, forests contain ~70% of all plant C and ~20% of all soil C. Furthermore, the average C content of forest soils is relatively high: 120 tonnes of C ha^{-1}, whereas the mean value of all ecosystem soils is of 79 tonnes of C ha^{-1} (Amthor, 1998). Because the forest floor comprises the most dynamic part of soil organic carbon (SOC) stock, understanding the mechanisms and factors that govern SOC dynamics in forest soils is important to predict the effects of forest ecosystem management on SOC stock (Lal, 2004; Yanai et al., 2003).

There is debate about whether harvesting forests affects soil and forest floor carbon content (Brais et al., 1995; Covington, 1981; Mattson and Smith, 1993; Seely et al., 2002), or has no effect at all (Johnson, 1992; Johnson and Curtis, 2001; Yanai et al., 2003). Substantial losses of C from vegetation and soils can be caused by harvesting (Houghton, 2003). Soil C storage may initially decline after clearcutting, because inputs from plants are too low to counteract losses by soil respiration. Intensive forest management may also lead to long term decreases in soil organic matter (SOM) content (Harmon et al., 1990). On the other hand, regenerating forests and plantations may represent important C sinks as a result of storage in both plant biomass and soils (IPPC, 2000). In addition, this debate is driven by the fact that forest ecosystems were rarely studied with regards to their temporal dynamics while it has been demonstrated, by means of humic

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epipedon morphological description, that changes in SOM dynamics occur with forest ageing (Aubert et al., 2004).

Mechanistic C sequestration studies usually focus on: (1) the search for correlations between total SOM accumulation and ecosystem driving variables (e.g. soil texture, soil structure, annual rainfall, temperature), or (2) comparisons of SOM fractions among treatments (Degryze et al., 2004). Fractionation implies the separation of the total SOM into different pools that are thought to be functionally homogeneous with respect to physicochemical properties and turnover rate. It can be carried out by physical or chemical means. The use of physical fractionation in studies of SOM turnover has increased steadily over the past two decades (Christensen, 2001). Physical fractionation of soil according to particle size supported by chemical, biological, and physical analyses of the fractions obtained has proven to be a useful tool in process-oriented SOM research (Christensen, 1992; Mathers, 2000).

In order to estimate the effect of silvicultural rotation on SOM, we assessed the quantity and the quality of SOM during a temperate managed beechwood rotation. Our objectives were (i) to report patterns in SOC stocks, and (ii) to quantify SOC dynamics in humic epipedon during a managed intensive beechwood rotation.

2. Material and methods

2.1. Study site

The study was carried out in even-aged pure beech stands of the Forêt Domaniale d'Eawy (Haute-Normandie, France). The climate is temperate oceanic with a mean annual temperature of +10 °C and a mean annual precipitation of 800 mm (Brêthes, 1984). All stands were located on a plateau with more than 80 cm of loess as parent material. Soils are LUVISOLS, according to the "Référentiel pédologique" (Baize and Girard, 1998) and are equivalent to LUVISOLS in the World Reference Base (FAO, 1998). Stands were managed by the French Forestry Service (ONF), essentially for beech timber production. All the selected stands were grown from artificial plantation.

Chronosequences used in this study are false time series, which integrate independent forest stands with their distinct history into one unit, thus, substituting space for time. In order to minimize the resulting variability, stands within a chronosequence should be as identical as possible in their stand characteristics (Cole and Van Miegroet, 1989; Klinger and Short, 1996). We thus selected 15 stands, taking maximal care to minimize stand characteristic differences by choosing neighbouring stands in the same altitude, on the same bedrock and with a similar topography. This stand set encompassed the following silvicultural phases: first thinning, refining, amelioration and regeneration (Table 1, mean ages were 29, 63, 132, and 186 years old, respectively). The definition of these silvicultural phases followed the description provided by Aubert et al. (2003). First thinning stands chosen for the present work corresponded to the older stands of Aubert et al.'s (2003) cleaning phase. Because of the progressive abandonment of artificial plantation by the managers these two last decades, regeneration phase now corresponds to an assisted natural regeneration within which beech saplings were planted after site preparation only if natural beech renewal had failed.

2.2. Sampling

Soil and humic epipedon were sampled simultaneously during March and April 2005, within a sampling area of 40 m × 20 m established in each selected stand. Both soil and humic epipedon samplings were chosen based on some excluding criteria. Extreme locations such as pits and mounds caused by treefall or tractor tracks were avoided and samplings were situated as far as possible from tree trunks (at least 2 m) to avoid organic matter accumulation and acidification (Beniamino et al., 1991).

2.3. SOC stocks in Ce depth

2.3.1. Estimation of SOC stocks

According to the acidic context of Eawy soil (Table 2), SOC is equivalent to total soil carbon. Currently, SOC stock for a given soil strata is estimated by extrapolating a SOC content per

Table 1
Description of the 15 selected stands reconstituting a silvicultural rotation by the space-for-time substitution procedure

Stand age (years)	Silvicultural phase	Last cut year	Wood uptake ($m^3\ ha^{-1}$ since 1980)	$pH_{[H_2O]}$
28	First thinning	1997	127.3	3.82
28	First thinning	1998	191.8	3.78
30	First thinning	1996	235.1	3.82
61	Refining	1997	105.0	3.79
61	Refining	1997	112.6	3.97
65	Refining	1998	128.4	3.86
118	Amelioration	1998	138.7	3.91
127	Amelioration	1995	149.0	3.88
136	Amelioration	1995	162.4	3.96
147	Amelioration	1993	167.7	3.94
177	Regeneration	1996	255.3	3.97
179	Regeneration	1991	93.4	3.83
182	Regeneration	1998	127.1	4.03
197	Regeneration	1997	193.6	4.21
197	Regeneration	1997	115.8	4.12