Soil Biology & Biochemistry 41 (2009) 1674–1683

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Soil organic matter in soil physical fractions in adjacent semi-natural and cultivated stands in temperate Atlantic forests

Nahia Gartzia-Bengoetxea [a,*], Ander González-Arias [a], Agustín Merino [b], Inazio Martínez de Arano [a,1]

[a] NEIKER-Tecnalia, Basque Institute for Agricultural Research and Development, Zamudio Technology Park 812, E-48160 Derio, Bizkaia, Spain
[b] University of Santiago de Compostela, Escuela Politécnica Superior, Campus Universitario, E-27002 Lugo, Spain

ARTICLE INFO

Article history:
Received 25 November 2008
Received in revised form
30 April 2009
Accepted 18 May 2009
Available online 12 June 2009

Keywords:
Soil aggregates
C-dynamics
Temperate forests
Pinus radiata
Mechanization

ABSTRACT

Changes from natural tree species to rapidly growing exotic species as well as intensification of forestry operations with heavy machinery can lead to changes in the quantity and quality of organic matter inputs to soil and to disruption of soil physical structure. These two ecosystem properties are tightly linked to organic matter dynamics. Five adjacent forest stands were selected to study soil organic matter dynamics in soil physical fractions. On one hand, two semi-natural broadleaved forests (*Quercus robur*, *Fagus sylvatica*) and an adult radiata pine plantation (40-year-old,) in order to study the effect of species change on these parameters, and on the other, a chronosequence of *Pinus radiata* plantations (40-year-old; 3-year-old; 16-year-old), to study the effect of mechanization during harvesting and intense site preparation. Samples of intact topsoil (0–5 cm) were collected and aggregate-size distribution, mean weight diameter (MWD), total C and N, particulate organic matter (POM)-C, POM-N and microbial biomass-C were determined in each aggregate size fraction. Microbial respiration and nitrogen mineralization were also assessed in each aggregate size fraction, during a 28 day incubation period.

Losses of POM-C and POM-N in the bulk soil due to mechanical site preparation were high relative to total soil C and N, which suggests that POM is a sensitive parameter to the effect of mechanization. The ratio C-POM:SOM was significantly related to MWD ($R^2 = 0.75$, $P < 0.001$) reflecting that POM may play a key role in the topsoil aggregate formation in these stands. Semi-natural stands had a higher proportion of macroaggregates (0.25–2 mm) than the cultivated adult one. Megaaggregates (>2 mm) were the most abundant class in mature stands (82–92%), whereas macro- and microaggregates (<2 mm) were the most abundant ones in the intensely soil prepared *P. radiata* plantation (49%).

Indicators for sustainable forest management related to soil organic matter should not only be assessed in terms of total C stocks but also with respect to sensitive organic matter and its degradability in different size classes.

1. Introduction

Conversion of native forests and afforestation of agricultural or abandoned land into cultivated forests of rapidly growing exotic species is a worldwide phenomenon induced by increasing population growth and demand for wood and fibres. In addition, the increasing concurrence in global markets is putting greater pressure on forest ecosystems, which is usually accompanied by intensification of harvesting and site preparation practices. Cultivated radiata pine (*Pinus radiata* D. Don) forests cover more than 4×10^6 ha in the southern hemisphere (mainly in Chile, New Zealand, Australia and South Africa) but only around 300,000 ha in the northern hemisphere, mostly in northern Spain (Lavery and Mead, 1998). In this region, natural forests, previously dominated by *Quercus robur* L, were mostly felled by the end of the XIX century and were reforested during the XXth century with radiata pines. It is known that dominant tree species affect the availability and biochemical composition of organic matter inputs to soil (Leckie et al., 2004) and different root systems also affect aggregation differently, in relation to different root properties, exudates and functions (Chan and Heenan, 1999).

The current plantation management in cultivated radiata pine forests in the Basque Country involves a clear-cut regime with rotation lengths between 30 and 40 years, harvesting with saw chain and skidding, and mechanical site preparation prior to planting with processes such as blading and ripping. These forestry practices may alter the amount and turnover rates of soil organic matter (SOM). Thus, harvesting and site preparation result in

* Corresponding author. Tel.: +34 94 403 4325; fax: +34 94 403 4310.
E-mail address: ngartzia@neiker.net (N. Gartzia-Bengoetxea).
[1] Present address: USSE-Southern Europe Forest Owners Union, Larrauri 1, E-48160 Derio, Spain.

0038-0717/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2009.05.010

considerable disturbance to the forest floor and mineral soil and a consequent redistribution of organic matter across the site (Merino et al., 2004); ploughing and/or ripping breaks soil aggregates and exposes the previously protected organic matter to microbial decomposition (Ashagrie et al., 2007). Apart from the detrimental effect of harvesting and site preparation on soil structure and soil quality (Horn et al., 2004), the released CO_2 as a consequence of increased mineralization may contribute to global warming (IPCC, 2000).

Maintenance or enhancement of SOM in forest ecosystems is crucial for sustainable use of forest resources because of the multiple effects of SOM on nutrient dynamics (Binkley, 1995), C cycle (Nambiar, 1996) and soil structure.

SOM improves soil structure by enhancing aggregation and therefore it influences soil water movement and retention, aeration, erosion, nutrient recycling, root penetration and production (Bronick and Lal, 2005). The role of physical structure in determining SOM sequestration and turnover has generated much interest in recent years (Six et al., 2004; Liao et al., 2006). The relationship between organic matter and soil aggregation was proposed by Tisdall and Oades (1982) in a conceptual model. These authors considered three different cementing or binding agents: temporary, transient and persistent. Persistent binding agents consist of degraded, aromatic humic materials associated with polyvalent metals strongly sorbed to clays, responsible for the construction of microaggregates (0.053–0.250 mm). In contrast, temporary and transient binding agents such as polysaccharides, roots and hyphae are responsible for the stabilization of microaggregates into macroaggregates ($>$0.25 mm). Alternatively, macroaggregates may form around particulate organic matter (POM). POM is composed of partially decomposed plant and animal residues (Christensen, 2001) and as POM is decomposed and microbial exudates are released, the macroaggregate becomes more stable, the C:N ratio decreases, and microaggregates form inside (Oades, 1984). Because of the relatively labile nature of temporary and transient binding agents, soil management has a greater effect on macroaggregates and the organic matter retained on them, than on microaggregates, which have more stabilized and humified organic matter (Six and Jastrow, 2002).

The effects of tree species on soil aggregation and of intensive forest practices on soil aggregate distribution may be of great importance in regulating accretion or depletion of SOM in temperate Atlantic forests. Two of the criteria considered in the Lisbon Resolution L2 on Pan-European criteria and Indicators for Sustainable Forest Management deal (i) with the forest contribution to carbon global cycles and (ii) with the maintenance of protective functions (notably soil and water) (MCPFE, 1998). To gain insights into the interactions between SOM structure and dynamics in temperate forests, natural aggregates from the field should be studied (Pulleman and Marinissen, 2004).

The study of these parameters in semi-natural forests is of interest as they may be considered as a target value to which compare the values found in managed stands when sustainability of the management wants to be assessed. On the other hand, the values found in adult stands that have been managed with the best known silvicultural practices, may be considered as a minimum target to which compare recently managed forest plantations. For this reason, five adjacent forest stands that presented the same soil parent material, geomorphology and climate, were selected as a case study. Three of these stands presented different dominant species, and another two were selected as part of a chronosequence of radiata pine plantations that differed in the time when they were intensely soil prepared. The objectives of this study were to (i) gain insight in the distribution of the stock of soil C and N pools in the topsoil of adjacent temperate stands that only differ in management (considered as species change and time since intense site preparation), (ii) understand the effect of this forest management on the topsoil organic matter dynamics and on its relationship with aggregation and (iii) to elucidate the role of topsoil aggregates in active C and N pools in response to this forest management.

2. Materials and methods

2.1. Site description

The study site (30T, 534075, 4783284) was selected as an example of the landscape of the Atlantic temperate forest landscape in the Basque Country. The selected stands were in close proximity (maximum distance between them was 100 m), and were selected to have developed on the same parent material (sandstone) (EVE, 1994). The soil was classified as a Dystric Regosol (FAO, 1998). Climate in this region is mesothermic, characterized by cool, moist summers and mild, wet winters. The mean air temperature is 18.7 °C in summer and 9.6 °C in winter. The mean annual precipitation ranges between 1200 and 2000 mm (Ortubai, 1995) and is distributed rather evenly through the year, although maximum levels are observed in autumn and in spring (González-Arias et al., 2006). All the studied stands faced south and were developed on similar slopes.

The strategy of the study was to evaluate three representative stands of two mature semi-natural forests (*Q. robur* L. and *Fagus sylvatica* L., hereafter referred to as oak and beech) and a nearby first-rotation and non-mechanized cultivated *P. radiata* D. Don plantation (hereafter referred to as pine 40y) to evaluate soil properties beneath different tree species. These mature stands showed tree densities of around 300 trees per hectare, although mature pine stand showed higher basal area (90 m^2 ha^{-1}) than oak and beech stands (64 and 63 m^2 ha^{-1}, respectively). In addition, two stands of radiata pine plantations were sampled from two adjacent clear-cut sites as a part of a chronosequence. The mechanical site preparation and consequent plantation of these stands was done 3 and 16 years before the present study was conducted (hereafter referred to as pine 3y and pine 16y): These younger stands were planted on formerly radiata pine plantations. These former plantations were established with no mechanical preparation of the site. The chronosequence consisting of pine 40y, pine 3y and pine 16y was selected to evaluate the effect of heavy mechanized forest operations 3 and 16-years after disturbance. In terms of sustainability of the soil management in regular forest operations, the best known practice was considered to be as the least aggressive to the soil, and as such, the non-mechanized one was selected for this study (pine 40y). Moreover, pine 3y and 16y are supposed to have been in a similar stage to pine 40y before harvesting. The pine 16y stand had a tree density of 1010 trees ha^{-1} and a basal area of 18 m^2 ha^{-1} and pine 3y stands was established using a 3×2 m grid. The mechanized forest operations included (i) harvesting of the clear-cut trunks with skidders and (ii) site preparation with a bulldozer. This last operation consisted in blading that was done to eliminate harvest residues and competing vegetation, and in down-slope ripping to ameliorate the physical structure of the soil. During the blading operation, the first centimetres of the mineral soil might be excavated together with harvest residues and surface organic material (Macdonlad et al., 1998); down-slope ripping consists of deep ploughing ($\approx$50 cm) following the maximum slope of the stand.

2.2. Soil sampling

Sampling was carried out in April of 2005. In each of the studied stands, three pits were dug and 1 undisturbed soil sample was taken from the first 5 cm ($\approx$2000 cm^3) in each pit after having removed