COMPARING THE POTENTIAL CARBON MINERALIZATION ACTIVITY OF THE SOIL ORGANIC MATTER UNDER TWO BROADLEAF AUTOCHTHONOUS TREE SPECIES FROM THE NW OF SPAIN (*QUERCUS ROBUR* L., *BETULA ALBA* L.)

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Abstract

The importance of the soil organic matter pool on the terrestrial carbon (C) cycle is clearly reflected by the fact that every year around 10% of the atmospheric C circulates throughout the biomass and the soil. Not only the size of this pool but also the composition and lability of the organic compartments have a notable influence on the soil CO_2 emissions, since its nature determines the resident times and persistence of the different C compounds into the soil. Therefore, two different types of deciduous forests of the temperate-humid zone (*Quercus robur* L. or *Betula alba* L.) were studied in order to evaluate the biodegradative processes of their soil organic matter. In Galicia (Northwestern Spain), 24 permanent forest plots were established to determine their potential C mineralization activity using long term incubation experiments that were carried out under laboratory controlled conditions. The cumulative data of the potential soil CO_2 effluxes were fit to a double exponential kinetic model that considers two C pools of different lability and different instantaneous mineralization rates in order to estimate the labile and recalcitrant C pools in these soils. Differences on the total soil C content as well as on the soil organic matter mineralization kinetics between both forest types were found and the implications of the results obtained in the global warming mitigation strategies are discussed. The results obtained are useful not only to evaluate the quantity of CO_2 released to the atmosphere from these Atlantic forests but also to contribute to a better prediction of the C balance in a global warming scenario.

Key words: *Betula alba*, carbon mineralization kinetics, CO_2 release, global warming, labile and recalcitrant carbon pools, *Quercus robur*, terrestrial carbon cycle.

Introduction

The Earth's carbon (C) budget is distributed among the different biogeochemical compartments, with permanent flux exchanges between them. Within terrestrial ecosystems, forests play an important role in sequestering and storing C (Sampson 1995) and deciduous forests from the mild temperate zone of the Northern Hemisphere are one the major terrestrial biomes.

In the NW of Spain (Galicia), located within the temperate-humid zone, both coniferous and deciduous forest types are found. However, the typical Galician forest is formed by different species of decidious trees, like oaks and birches, these broadleaf forests being valuable natural resources. Pedunculate oak (*Quercus robur* L.) is the third most abundant tree species in Galicia (Xunta de Galicia 2001), with annual harvest volume of 74,500 m^3 in the period 1995-2001. Oak forests cover 188,000 ha in this region (Xunta de Galicia 2001) and are mainly derived from natural regeneration (Gorgoso-Varela et al. 2008). Birch (*Betula alba* L.) stands currently cover 32,000 ha and birch is the fifth most abundant species in terms of number of trees in Galicia, after *Eucapyptus globulus*, *Pinus pinaster*, *Quercus robur* and *Quercus pyrenaica*.

Soils have a great importance on the global C cycle due to their long term capacity to retain C (several centuries for the more recalcitrant compounds) as well as due to the magnitude of the C fluxes involved, since every year around 10% of the atmospheric C circulates throughout the biomass and the soil (Oades 1989). In particular, soil C pool is a major component of the global C cycle (Lal and Follett 2009) and it is the key factor in stabilization, accumulation, and dynamics of terrestrial organic C (Andreux 1996). It also strongly influences sustainability, fertility, and productivity of forest ecosystems (Schoenholtz et al. 2000, Wander and Drinkwater 2000), particularly in acidic and sandy soils where fertility is mainly determined by soil organic matter content and quality (Fernandez et al. 2006). Thus, understanding soil organic matter dynamics and the contributions of different organic pools to the total CO_2 effluxes from forest soils as well as the mechanisms involved in soil organic matter mineralization kinetics is important since it influences main forest and environmental processes from a climate change perspective.

Therefore, the aim of this research is to study the soil C dynamics in two different types of deciduous forests (*Quercus robur* L. or *Betula alba* L. ecosystems) located in Galicia (Northwestern Spain) in order to determine the potential C mineralization activity and to compare the soil organic matter quality under these two types of temperate ecosystems.

Methods and Study Area

The oak and birch forest ecosystems studied, developed over acidic (granite or schists) parent material (Fig. 1) and located in the NW of Spain, were selected to represent the whole range of stand densities, undergrowth types and growing conditions in Galician forests for these two tree species. None or scarce silvicultural treatments were applied to the forests selected and the spatial distribution of the different plots accompanied by the main meteorological records corresponding to the period of study (temperature and rainfall values during the year 2009) are described by Fernandez et al. (2010).

After the removal of the litter and the duff, a representative soil sample (composed by mixing 24 subsamples regularly taken following a squared

Fig. 1. Soil profiles developed over acidic parent material: oak forest over granite (a), oak forest over schists (b) and birch forest over schists (c).

pattern) from the upper layer of the A horizon (0–15 cm) were collected in winter to determine the main soil characteristics. The soil pH was measured using a 1:2.5 soil:water ratio. The field capacity was assessed at 10 kPa in a Richard's membrane-plate extractor. Total organic C was determined by dry combustion in a Carmhograph 12 (Whostoff, Germany), with primary and secondary ovens at 90ºC and 40ºC, respectively. Total organic N was determined by Kjeldahl digestion using the method developed by Bremner (1965).

Fig. 2. Respirometric system used to perform the soil incubation experiments.

For each forest plot, a long term incubation of representative soil samples was carried out under controlled conditions

(28ºC and 75% field capacity). During 3 months, the C mineralized was periodically determined by measuring the CO_2 produced during the biodegradative process (Fig. 2). The cumulative data of the potential soil CO_2 effluxes were fit to a double exponential kinetic model (Eq.1) that considers two C pools of different lability and different instantaneous mineralization rates in order to estimate the labile and recalcitrant C pools in these soils.

Eq.1: $C_t = C_0(1\text{-}e^{-kt}) + (C\text{-}C_0)(1\text{-}e^{-ht})$

Ct: cumulative C ($g.kg^{-1}$) released after time t (d), C_0: potentially mineralizable C in a labile pool with an instantaneous mineralization rate *k* (d^{-1}), C: total amount of C ($g.kg^{-1}$) present in the soil sample, ($C\text{-}C_0$): amount of C ($g.kg^{-1}$) in a recalcitrant pool with an instantaneous mineralization rate *h* (d^{-1}).

Statistical analyses were performed using the computer software SPSS 15.0 (2006). ANOVA test was applied to analyse the possible variations between oak and birch soils.

Results and Discussion

Soils from the selected forest plots, all with acidic parent materials, exhibited pH values between 4.0 and 5.2 (Table 1). Despite the high variability of the soil organic matter content of the different forest ecosystems, the mean C content of soils from oak plantations (87 g $C.kg^{-1}_{d.s.}$) was significantly higher (ANOVA, $p<0.05$, $n=24$) than the mean C content from birch forests (66 g $C.kg^{-1}_{d.s.}$). The values found in these soils are in agreement with the results obtained for different types of forest soils of this region (Sánchez-Rodríguez et al. 2002; Fernandez et al. 2004; Diaz-Maroto et al. 2005,

Table 1. Range of values of some edaphic parameters related to the soil C cycle for oak and birch forest ecosystems.

Parameters	*Quercus robur* L.		*Betula alba* L.	
	Granite	Schists	Granite	Schists
Soil pH	4.0–5.2	4.3–4.9	4.1–4.9	4.4–4.9
Total soil C, g $C.kg^{-1}$ d.s.	56.6–136.2	64.1–105.4	47.1–113.1	27.9–85.2
Total soil N, g $N.kg^{-1}$ d.s.	3.3–6.8	4.2–6.7	3.3–7.7	2.7–5.7
C-to-N ratio	14–20	13–18	14–16	13–17
C mineralized, g $C.kg^{-1}$ d.s.	1.51–3.72	2.08–3.55	1.33–3.07	1.17–2.65
C mineralization coefficient, %	1.98–3.20	2.73–3.38	2.25–3.15	2.77–5.65
Soil labile C, %	0.62–1.36	0.65–1.02	0.33–1.15	0.96–1.28

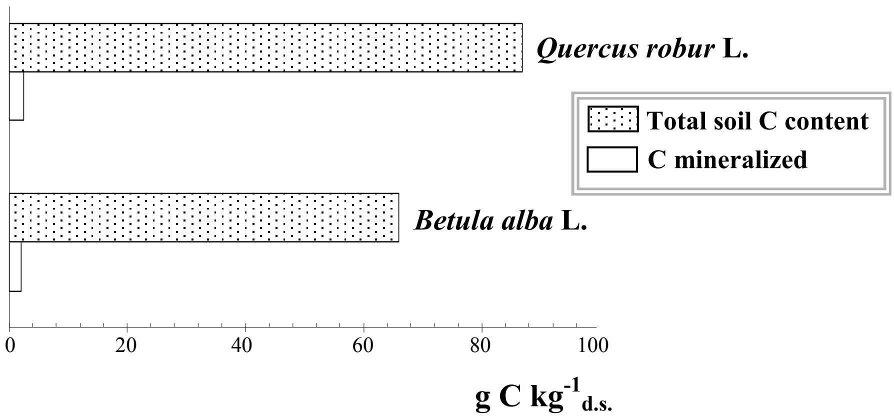

Fig. 3. Total soil C content and quantity of C mineralized at the end of the incubation.

2007; Fernandez et al. 2006) and with soils from other countries of similar latitudes (Mansson and Falkengren-Grerup 2003). Also, differences on the soil organic matter quality between both tree species were observed, oak ecosystems showing, in general, more elevated values of the C-to-N ratio (mean C-to-N ratio = 18±2) as compared with birch forests (mean C-to-N ratio = 15±2). Thus, the organic matter of both types of ecosystems could be considered, according to the classification of temperate forest humus (Duchaufour 1977), an intermediate type between *moder* and *mull*.

The averaged quantity of CO_2-C evolved from oak soils at the end of the incubation (2.4 g C.kg$^{-1}_{d.s.}$) was slightly higher than the amount released by birch (2.1 g C.kg$^{-1}_{d.s.}$) soils (Fig. 3).

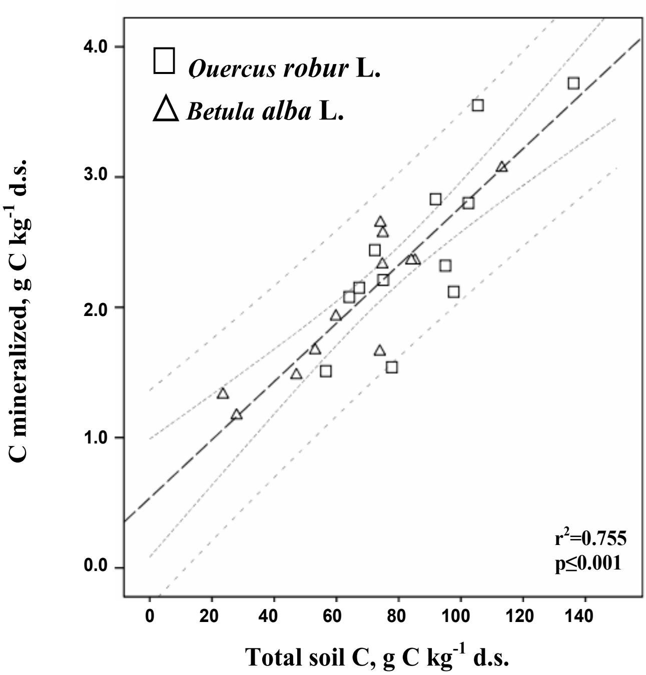

Fig. 4. Relationship between the quantity of C mineralized and the total soil C content in oak and birch forests.

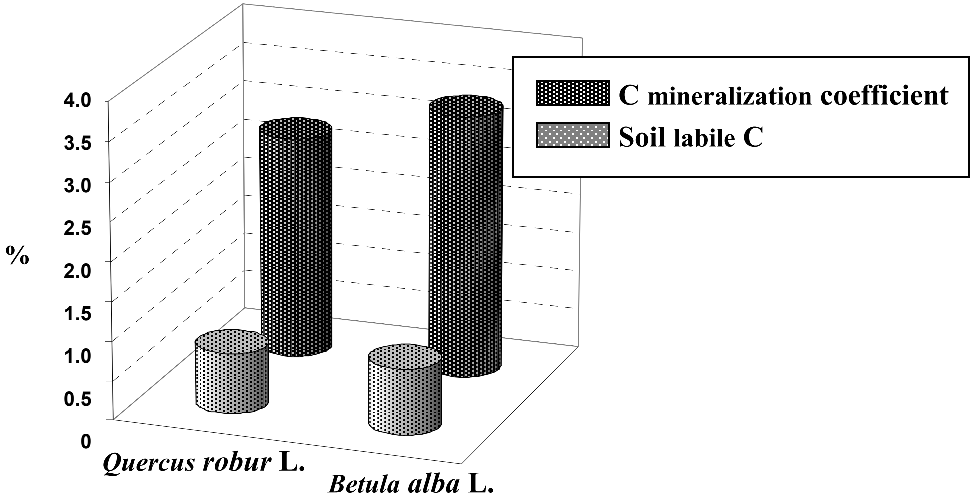

Fig. 5. C mineralization coefficient and percentage of labile C for oak and birch forests.

A significant correlation between the C mineralized by the soil during the incubation period and the total soil C content was found ($P<0.001$) in both type of forests (Fig. 4).

On the other hand, the mean soil C mineralization coefficient was slightly higher for birch (3.3%) ecosystems as compared with oak (2.8%) forests (Fig. 5), this activity index being positively correlated with the proportion of labile C in the soil ($r^2 = 0.202$, $P<0.05$).

Also, the C mineralization coefficient statistically correlated with the total soil C content in birch forests but no significant correlation was observed in oak ecosystems (Fig. 6). In general, the values of this activity index can be considered as relatively low, but typical for acid soils from the same area (Fernandez et al. 2006). Although differences on the soil organic matter characteristics between oak and birch ecosystems were found, differences on the C mineralization kinetics were not significant, maybe due to the intraespecific variability derived from the high number of factors taken into account.

Conclusions

Based on these experimental results, the following conclusions can be drawn:

- Within this temperate-humid zone, oak forests exhibited a significantly higher soil C content than birch plantations.
- In general, for both tree species, a relationship between the total soil C content and the quantity of C mineralized during the 12 weeks of incubation was found, highly organic soils potentially releasing more C effluxes than less organic ones.
- The soil C mineralization coefficient strongly correlated with the soil organic matter content for birch forests, but not for oak plantations.
- These results show the potential quantity of CO_2 that can be released to the atmosphere from these Atlantic

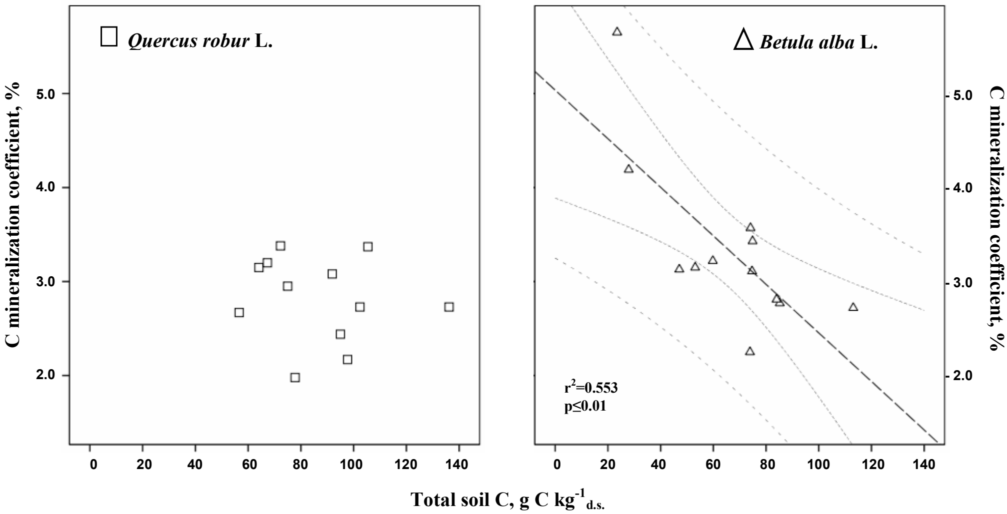

Fig. 6. Relationship between the total soil C content and the C mineralization coefficient in oak and birch forests.

forests and can contribute to a better prediction of the C balance in a global warming scenario since:

i) The success of a sustainable silviculture seems to be related with both mineralization indices: with the C mineralization coefficient in *B. alba* forests and with the total quantity of C mineralized in *Q. robur* plantations.

ii) In comparison with birch forests, oak ecosystems seems to show a higher soil C retention capacity due to a higher resistance to biodegradation of the recalcitrant C pool of their soil organic matter.

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