

Impact of tree species replacement on carbon stocks in forest floor and mineral soil

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Abstract

This study aims at evaluating the influence of replacing areas of *Quercus pyrenaica*, which represents native vegetation of Serra da Nogueira, NE of Portugal, by *Pseudotsuga menziesii* on carbon stocks in forest floor and mineral soil. Three sampling areas were selected in adjacent locations with similar soil and climate conditions. The first area, covered by *Quercus pyrenaica* (QP), represents the original soil. The second area is in a 40 years old stand of *Pseudotsuga menziesii* (PM40), and the third one, also under *Pseudotsuga menziesii*, is 15 years old (PM15). In each sampling area, at 10 randomly selected points, samples were collected in the forest floor (0.49 m² quadrat) and in the soil (at 0-5, 5-10 and 10-20 cm depth). The forest floor stores 17, 13 and 6% of total carbon for PM40, PM15 and QP, respectively. Four decades after species replacement, a soil organic carbon loss is observed, although no significant differences were found when comparing soil under introduced (PM) with original species (QP). A carbon loss of around 30%, in PM15, and gains of about 10%, in PM40, are computed when considering mineral soil and forest floor together.

Keywords: *Quercus pyrenaica*; *Pseudotsuga menziesii*; forest floor; soil organic carbon.

1. Introduction

The increase in atmospheric carbon content, as expected considering actual trends, draws attention to the highly valuable role of forest ecosystems in the global carbon cycle (Eswaran et al., 1993). The majority of the native vegetation in Iberian peninsula (Portugal and Spain) have been replaced by other forest species, particularly fast-growing conifers plantations. Although this replacement may have beneficial economic consequences, it is essential to understand environmental effects such as in carbon sequestration for mitigation of greenhouse gases. The knowledge of the differences among species in what regards C sequestration should be a decision support tool when introducing new forest species and can be used strategically to reach environmental goals (Oostra et al., 2006; Schulp et al., 2008; Vallet et al., 2009).

Species replacement implies changes in carbon stocks in forest floor and soil organic matter (Peltoniemi et al., 2004) because tree species litter quantity, quality and distribution in soil horizons have high influence in carbon storage (Oostra et al., 2006). Decomposition rate of plant residues can be slower or faster, depending on their nature. In general, it is accepted that organic residues from coniferous species decompose more slowly than broadleaved species, for example, due to the presence of non-hydrolyzable polyphenolic compounds in litter (Faulds and Williamson, 1999). On the other hand, fast-growing species would accumulate carbon more rapidly than slow-growing species, but several studies shown that substitution leads to a carbon

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loss (Schroth et al., 2002; Wang and Wang, 2007; Vallet et al., 2009). Carbon stored in forest ecosystems depends fundamentally on forest age and management practices (Post and Kwon, 2000; Paul et al., 2002; Pregitzer and Euskirchen, 2004). Species choice is actually a management option to increase carbon storage (Vallet et al., 2009).

The main objective of the present study was to quantify the impact of replacing a native hardwood species (*Quercus pyrenaica*) by a fast-growing conifer plantation (*Pseudotsuga menziesii*) on carbon stocks in forest floor and mineral soil, and its persistence through time.

2. Methodology

The study area was located in Serra da Nogueira, northeast of Portugal (41° 45'N and 6° 52'W), in the range between 1000 and 1100 m altitude. The annual average temperature is 12° C and annual average precipitation is 1100 mm, concentrated from October to March (INMG, 1991). The native vegetation is *Quercus pyrenaica* (*QP*), which occupies about 6,000 ha and represents the area of *QP* most extensive in Portugal. Over the last decades, some of the *QP* area have been replaced by fast-growing species, mainly *Pseudotsuga menziesii*, process where the fires have had an important role. Soils are classified as Orthi-Dystric Leptosols derived of schists (Agroconsultores and Coba, 1991).

To assess the impact of species replacement on carbon stocks in forest floor and mineral soil three sampling areas were selected in adjacent locations with similar soil and climate conditions. Selected study species were 15 year old (*PM15*) and 40 year old (*PM40*) stands of *Pseudotsuga menziesii* and stands of *QP*, the latter representing the original soil. The stands characterization is presented in Table 1.

Table 1: Mean stand characteristics for *Pseudotsuga menziesii* and *Quercus pyrenaica*.

Stands	Number of stems (trees ha ⁻¹)	Age (years)	Dominant height (m)	Mean diameter (cm)	Basal area (m ² ha ⁻¹)
<i>P. menziesii</i> (<i>PM40</i>)	3800	40	20.1	27.7	229.3
<i>P. menziesii</i> (<i>PM15</i>)	6700	15	13.9	16.6	144.3
<i>Q. pyrenaica</i> (<i>QP</i>)	19300	-	8.5	7.3	81.6

In each one of the three stands (*PM15*, *PM40*, *QP*) 10 areas of 70 x 70 cm (0,49 m²) were randomly established. In each one of these, the forest floor, defined as organic material deposited over mineral soil, was collected. Forest floor samples were dried at 65 °C for 72 h to determine dry mass.

Total soil organic C down to 20 cm depth (sampled in the same points where forest floor had been removed) was calculated from C concentrations determined in samples collected in the 0-5, 5-10 and 10-20 cm soil layers. Bulk density (BD) was estimated at the same depths using the equation:

$$BD = 100 / (\%OM / BD_{OM}) + ((100 - \%OM) / BD_{\min \text{ soil}}) \quad (1)$$

where OM is soil organic matter, BD_{OM} the bulk density of organic matter (assumed to be 0.244), $BD_{\min \text{ soil}}$ the mineral soil bulk density (assumed to be 1.64) (Post and Kwon, 2000; Paul et al., 2002).

Samples for soil C were air dried and sieved to determine the coarse fraction (> 2 mm). All samples of forest floor and mineral soil were analyzed for total C by dry combustion (ISO, 1994). Soil samples were tested with an acid-drop but no carbonates were detected, thus the total soil C was assumed to be comparable to soil organic C. Forest floor mass values were converted to carbon (t C ha⁻¹) multiplying these values by the C concentration in dry matter.

Soil organic carbon (SOC, t C ha⁻¹) was calculated multiplying C concentration by bulk density and thickness of the mineral soil layer with a correction for coarse elements content.

3. Results and discussion

Carbon concentration is significantly higher in forest floor under native species (*QP*), but the amount of organic residues accumulated on the soil surface is higher under the introduced species (*PM40* and *PM15*). The carbon stocks under *PM40* is about three times higher than the original soil, following the pattern *PM40* > *PM15* > *QP* (Figure 1). These results seem to be related to the decomposition rate, since under coniferous it is evident, on the surface, the presence of a large amount of slightly decomposed organic debris, unlike under the deciduous there is less amount of organic material, which suggests a more rapid decomposition and subsequent connection to the mineral fraction. Similar results were obtained by Rapp (1984) and Fonseca (1999). Among the conifers, differences also appear to be due to the age of the stands and the increase in density of canopy cover observed from *PM15* to *PM40*. In temperate forests, forest floor remain relatively constant or increase with age, reaching a peak after about 70 years of stand development (Pregitzer and Euskirchen, 2004).

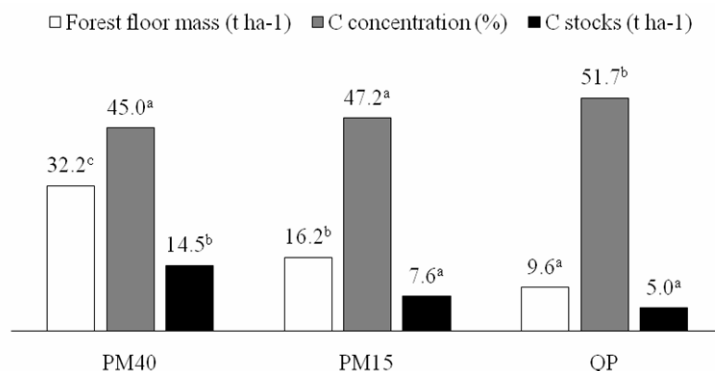


Figure 1: Forest floor mass (t ha⁻¹), C concentration (%) and C stocks (t ha⁻¹) in forest floor. For each variable, averages with the same letter are not significantly different (*P*<0.05).

The soil organic carbon concentration showed a vertical gradient for *QP*, with the highest values in the 0-5 cm layer and the lowest in the 10-20 cm layer. In introduced species (*PM15* and *PM40*) this gradient is not visible (Table 2), which may be related to disturbance caused by site preparation (Alcázar et al., 2002), and subsequent cleaning of stands.

Table 2: Changes in soil organic carbon concentrations (%) and soil organic carbon stocks (t C ha⁻¹) with soil depth for species observed, expressed as mean and standard deviation.

Depth (cm)	Stands		
	<i>PM15</i>	<i>PM40</i>	<i>QP</i>
	SOC concentration (%)		
0-5	3.0 (0.9) ^a	4.7 (1.0) ^b	5.8 (1.0) ^b
5-10	2.9 (1.0) ^a	4.7 (0.8) ^b	4.9 (0.3) ^b
10-20	3.0 (1.1) ^a	4.6 (0.8) ^b	4.5 (0.3) ^b
	SOC stocks (t ha ⁻¹)		
0-5	15.2 (4.0) ^a	21.7 (3.6) ^b	25.0 (3.1) ^b
5-10	13.6 (4.3) ^a	19.8 (2.8) ^b	21.5 (1.1) ^b
10-20	27.1 (9.2) ^a	40.6 (6.0) ^b	39.8 (2.1) ^b

For each layer and variable, averages with the same letter are not significantly different (*P*<0.05).

The 0-20 cm soil profile contained an average of 55.9, 82.1 and 86.3 t C ha⁻¹ in the *PM15*, *PM40* and *QP*, respectively (Figure 2). The proportion of soil organic carbon storage in relation to total (forest floor plus mineral soil 0-20 cm) was 87.5% for *PM15*, 84.5% for *PM40* and 94.6% for *QP*. All soil layers show significantly lower carbon storage values under *PM15*, than under *PM40* or *QP*. Despite the statistically non-significant differences found between *PM40* and *QP* in soil layers, after 40 years of species replacement there are still carbon losses in *PM40*, when compared to native vegetation (Figure 3). The differences observed in soils under *PM15* are mainly due to the shorter recovery time since disturbance caused during stand installation (Dick et al., 1998).

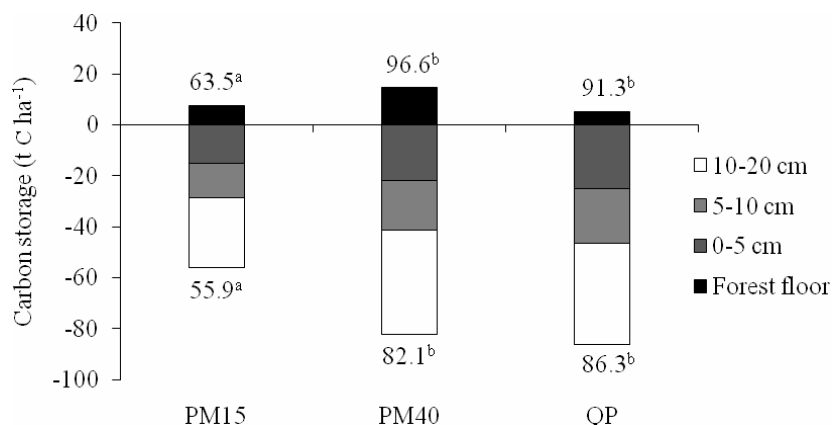


Figure 2: Total forest floor and soil organic carbon storage (numbers above bars in t C ha⁻¹) according to species. Numbers below bars indicate total soil organic carbon storage in t C ha⁻¹. For each layer, averages with the same letter are not significantly different ($P < 0.05$).

In *PM*, forest floor was a carbon sinks (2.6 and 9.5 t C ha⁻¹ for *PM15* and *PM40*, respectively) whilst mineral soil was a carbon source (30.4 and 4.2 t C ha⁻¹ for *PM15* and *PM40*, respectively), as compared with the native vegetation (*QP*) (Figure 3). Pregitzer and Euskirchen (2004) reported increases in C content of soil with age for the temperate forests, and this was also an overall trend found in our study for soil C pool (Figure 3).

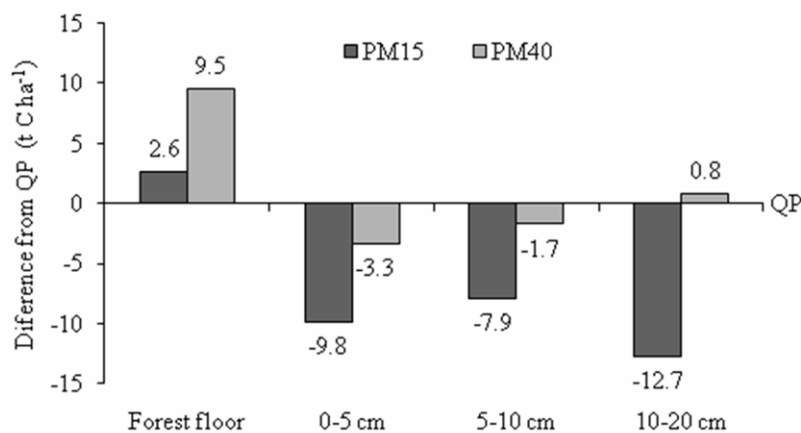


Figure 3: Gains (positive values) and losses (negative values) of carbon over time (t C ha⁻¹), due to the replacement of the species *QP* by *PM*.

The replacement of native vegetation (*QP*) by a fast-growing specie (*PM*) has effects on C stocks that depend on the time scale considered. The additional C storage of the *PM40* stands compared to *QP* is 5.3 t C ha⁻¹. After 15 years (*PM15*) the C loss reaches 27.8 t C ha⁻¹. There are many factors and processes that determine the distribution and rate of change in soil organic carbon storage when the type of vegetation and soil management practices are changed, among which stands age may assume great importance, as shown in this study.

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