Evaluation of Soil Organic Carbon Storage in a Sustainable Forest Chestnut Management Context

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Abstract

Soil organic carbon (SOC) is the major carbon (C) stock of the terrestrial biosphere with great importance for the balance of C at the global scale. So, a reliable estimate of the stored C in the mineral soil pool of forest ecosystems is of great importance. Inventory information on SOC stocks is very scattered, because of the inherent large spatial variability and the need of enormous sampling efforts. Therefore, traditional broadleaves species, less representative in the global context and scattered, as chestnut (*Castanea sativa* Mill.), are poorly sampled. Thus, this study was carried out to estimate the soil organic carbon (SOC) stock in traditional forests of sweet chestnut, based on in situ observations, to know the real contribution of this type of forests to the SOC stocks. This research was developed on old chestnut high forests for quality timber production submitted to a silviculture management close-to-nature located in Northern Portugal. At this stage the stands are close to self-thinning. Samples from soil profile at depths 0-10 cm, 10-30 cm and 30-60 cm were collected in 2002 and 2012. Besides the objective to know the real contribution of this type of forests to the SOC stocks, the evolution of the C storage was studied to also analyze the general capacity of the site concerning its sustainability and soil carbon pool. The cumulative amount of SOC shows an increase of 9% over 2002 in Marão and an increase of 4% in Bornes.

INTRODUCTION

Forests fix carbon dioxide from the atmosphere and sequester it in biomass, timber products and soils (stock effect). Nowadays, a reliable estimate of the stored carbon (C), in the mineral soil pool of forest ecosystems, is of great importance in helping Governments to make decisions in carrying out the Kyoto Protocol. In fact, inventory data have been used for making estimates of productivity, biomass and carbon at various scales from regional to global. These estimates can potentially be improved by including data from research sites where more intensive measurement programs have been implemented (Tuyl et al., 2005). Therefore, intensive measurements at representative sites of certain forest types provide important additional data to increase the reliability of estimates. Tuyl et al. (2005) consider that intensive and extensive measurements approaches are needed for regional analyses. Temperate forests are considered an important carbon sink, but the regional variation in C storage remains poorly understood, despite an increasing number of studies. Uncertainty about how much carbon is stored in temperate broadleaves forests is an important limitation for regional-scale estimates of carbon fluxes and improving these estimates requires intensive and extensive field studies of both above and belowground stocks.

Forest soil carbon storage is a significant component of the global C cycle, and is important for sustaining forest productivity (Nave et al., 2010). Forests contain about half of Earth's terrestrial C (1146×10^{15} g), and about two-thirds of this amount, is retained in soil pools (Dixon et al., 1994; Johnson and Curtis, 2001; Goodale et al., 2002).

In Portugal, information on soil organic carbon (SOC) stocks is very scattered. The large spatial variability as well as the enormous efforts associated to sampling are factors that make it difficult to massively collect such kind of information. Therefore, traditional broadleaves species as chestnut (*Castanea sativa* Mill.), less representative in the global context and with spotted distribution, are poorly sampled. In Portugal, this species is located essentially in the North from 400-1100 m a.s.l. Their main use is for nut production but, in the mountainous areas, coppice and high forest are particularly relevant, especially in deep forest soils. These chestnut ecosystems constitute discontinuities between conifer forests and are important for forest fire prevention, biodiversity, environmental protection as well as for timber production.

This research was developed on old chestnut high forests stands for high quality timber production submitted to a silviculture management close-to-nature, located in the mountains of Bornes and Marão (Northern Portugal), from a more-Atlantic-to-less-maritime influence (Regional level). At this stage the stands are close to self-thinning.

Thus, this study was carried out to estimate the SOC stock in traditional forests of sweet chestnut, based on in situ observations, to know the real contribution of this type of forests to the SOC stocks and to analyze the general capacity of the site concerning its sustainability and soil carbon pool.

MATERIALS AND METHODS

General Characteristics of the Sites

The present study was carried out in two high forest mature chestnut stands located in two mountains of Northern Portugal: Marão (41°14’46” N, 7°55’04” W) and Bornes (41°29’42” N, 6°55’12” W), from a more-Atlantic-to-less-maritime influence, respectively. The soils in the stands have developed over metamorphic rocks (schist). General characteristics of the stands are in Table 1.

Data Collection

To quantify the C and nutrient stocks in the mineral-soil compartment, 3 soil profiles were considered at each site. In each profile, soil samples were taken at depths 0-10 cm, 10-30 cm and 30-60 cm. Data were collected in 2002 and 2012 for the determination of the following parameters: organic C, and total nitrogen (N), phosphorous (P) and potassium (K) extractable.

Chemical Analysis

The soil samples were dried at 40°C and sieved. Chemical analysis was performed on the fine earth fraction (<2 mm). Organic carbon content was determined using the Walkey-Black method procedure. Nitrogen was determined after Kjeldahl digestion. The available P was measured colorimetrically after Égneir-Riehm method. Concentrations of K was analysed by flame emission spectrophotometry. Soil pH was determined with 1:2.5 soil paste and water (McLean, 1982).

Statistical Analysis

An ANOVA was performed to compare the carbon and nutrients concentration in the mineral soil by layers down to 60 cm depth in 2002 and 2012. A Tukey test was done for means multiple comparisons.

RESULTS AND DISCUSSION

The means of the three soil profiles for the carbon and nutrients concentration in the mineral soil by layers down to 60 cm depth in 2002 and 2012 are present in Table 2.

In general, C concentration decreased with soil depth but did not vary significantly from 2002 to 2012. C concentrations abruptly decrease with soil depth in Bornes where soil profiles are less developed than in Marão. In general, the concentrations of N, P and K in the mineral soil do not vary significantly from 2002 to 2012. Phosphorous was at very low levels in all sampled layers in the two study sites.

On average, 8 and 12 t ha^{-1} of N were stored between 0-60 cm of depth of the mineral soil of chestnut stands in the mountains of Bornes and Marão, respectively. The cumulative amount of N was maintained over 2002 in Marão and shows an increase of 14% in Bornes.

In relation to the SOC stock (Fig. 1), on average 84 and 180 Mg ha^{-1} of C were stored between 0-60 cm of depth of the mineral soil of chestnut high forest stands located in the mountains of Bornes and Marão, respectively. These variations could be related with the age of the stand and site conditions such as rainfall, slope and type of soil. In a decomposition study for the same sites Patrício et al. (2012), found lower N use efficiency in Marão than in Bornes and a decomposition rate for the recalcitrant pool of the leaves also faster in Marão. So, the higher N levels observed in Marão contribute to higher mineralization rates and concentrations of organic carbon in the soil. The high forest chestnut stands are closed to self-thinning, in other words, the process of density-dependent mortality. Self-thinning theory, predicts that the ratio between heterotrophic respiration and net primary production is constant as long as stand density is driven by small-scale (Luyssaert et al., 2008). Despite at this stage the stands are in natural balance, carbon returned to the soil by litterfall is still contributing to the increase in SOC.

CONCLUSIONS

The cumulative amount of SOC shows an increase of 9% over 2002 in Marão and an increase of 4% in Bornes. The currently available data indicated that SOC accumulation continues in chestnut high forests close to self-thinning.

The sylvicultural activity carried out with minimal interventions contributed to increase the carbon sequestration in the soil and, consequently, to the sustainability of the high forest chestnut stands.

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Tables

Table 1. General characteristics of the studied chestnut stands (Northern Portugal).

Chestnut stands	Marão	Bornes
Elevation (m a.s.l.)	900	800
Slope (°)	5-10	15-20
Main soil type[1]	Umbric Regosols	Dystric Cambisols
Mean annual temperature (°C)	11.5-12.0	11.9
Total annual precipitation (mm year^{-1})	2505	1009
Age (years)[2]	75	57
Density (tree ha^{-1})	360	1260
Mean DBH (cm)[3]	41.2±9.0	26.1±6.1
Mean height (m)[3]	28.7±2.7	22.4±2.7
Basal area (m^2 ha^{-1})[3]	157.9	223.8
LAI	4.9	4.4

[1]According to World Reference Base for Soil (FAO, 1988); [2]Age in 2012; [3]Values obtained in 2008.
(º): degree; DBH: Diameter Brest Height.

Table 2. Mean carbon and nutrients concentration in the mineral soil by layers down to 60 cm depth in 2002 and 2012.

Site	Depth (cm)	Year	pH (H_2O)	C	N	P	K
				g kg^{-1}		mg kg^{-1}	
Marão	0-10	2002	4.56	54.99±3.39 a	4.23±0.68 a	7.44±2.27 a	76.34±3.32 a
		2012	4.72	65.02±4.02 a	4.24±0.46 a	6.61±2.28 a	95.59±18.07 a
	10-30	2002	4.60	49.06±8.60 a	3.72±0.33 a	2.75±0.48 a	50.62±8.30 a
		2012	4.75	56.06±5.44 a	3.58±0.25 a	4.63±0.39 a	62.40±14.65 a
	30-60	2002	4.70	55.19±0.40 a	3.91±0.21 a	12.87±1.03 a	35.40±0.55 a
		2012	4.85	57.14±0.64 a	3.85±0.16 a	6.06±2.61 a	46.47±3.51 a
Bornes	0-10	2002	5.49	34.91±6.40 a	2.78±0.17 a	10.42±2.22 a	112.85±10.67 a
		2012	5.73	32.59±2.76 a	2.61±0.21 a	9.52±1.57 a	149.36±19.91 a
	10-30	2002	5.38	26.16±1.81 a	2.44±0.10 a	2.65±0.86 a	46.19±6.03 a
		2012	5.58	25.78±0.93 a	2.22±0.15 a	2.89±0.81 a	69.70±9.96 a
	30-60	2002	5.32	16.80±2.31 a	1.15±0.14 a	1.19±0.28 a	34.85±1,92 b
		2012	5.44	20.04±4.00 a	1.94±0.33 a	2.45±0.41 a	71.69±7.54 a

Values ± standard errors. Different letters in each column by site and year mean significant differences *p≤0.05* among means (Tukey test) of mean comparisons (*n*=3).

Figures

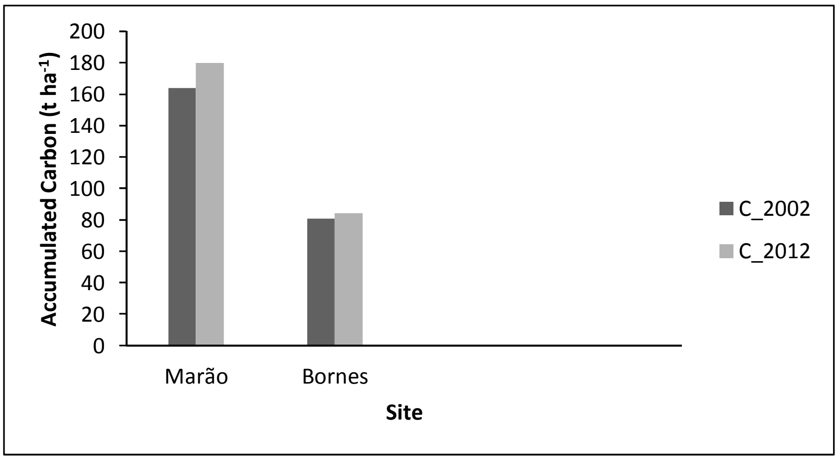

Fig. 1. Accumulated SOC by site.