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Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests

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ABSTRACT

An accurate characterization of tree carbon (TC), forest floor carbon (FFC) and soil organic carbon (SOC) in tropical forest plantations is important to estimate their contribution to global carbon stocks. This information, however, is poor and fragmented. Carbon contents were assessed in patula pine (*Pinus patula*) and teak (*Tectona grandis*) stands in tropical forest plantations of different development stages in combination with inventory assessments and soil survey information. Growth models were used to associate TOC to tree normal diameter (D) with average basal area and total tree height (H_T), with D and H_T parameters that can be used in 6–26 years old patula pine and teak in commercial tropical forests as indicators of carbon stocks. The information was obtained from individual trees in different development stages in 54 patula pine plots and 42 teak plots. The obtained TC was 99.6 Mg ha^{-1} in patula pine and 85.7 Mg ha^{-1} in teak forests. FFC was 2.3 and 1.2 Mg ha^{-1}, SOC in the surface layer (0–25 cm) was 92.6 and 35.8 Mg ha^{-1}, 76.1 and 19 Mg ha^{-1} in deep layers (25–50 cm) in patula pine and teak, respectively. Carbon storage in trees was similar between patula pine and teak plantations, but patula pine had higher levels of forest floor carbon and soil organic carbon. Carbon storage in trees represents 37 and 60% of the total carbon content in patula pine and teak plantations, respectively. Even so, the remaining percentage corresponds to SOC, whereas FFC content is less than 1%. In summary, differences in carbon stocks between patula pine and teak trees were not significant, but the distribution of carbon differed between the plantation types. The low FFC does not explain the SOC stocks; however, current variability of SOC stocks could be related to variation in land use history.

1. Introduction

The majority of carbon in the terrestrial pool is stored below ground in soils (Janzen, 2004). Total global carbon in soils constitutes between 1500 and 2000 Gtons; the majority of it stored in forest biomes (Janzen, 2004; Smith, 2004). Greenhouse gas emissions and the climatic change risk, make a reduction in atmospheric CO_2 concentrations necessary. However, most of the estimations and assumptions realized are uncertain for many ecosystems (Hendricks and Turkenburg, 1997; IPCC, 2000). In the last few years in particular, there has been increasing interest in the quantification of the biomass of forest ecosystems and its potential carbon fixation (Chave et al., 2005; Fearnside, 1996; Schulp et al., 2008; Sierra et al., 2007).

Preliminary results in forests show that traditional carbon estimation methodologies tend to under or overestimate real carbon stocks in different forest types (Tan et al., 2007; Federici et al., 2008; Schulp et al., 2008). Sometimes, these erroneous estimations are due to inaccurate assumptions of layers soil properties and the distribution of soil type with dominant vegetation (Milne and Brown, 1997). The results also indicate the relevance and a high heterogeneity in soil organic carbon (SOC), probably associated with the variability in topography, stoniness, parent material, soil depth and microclimate, on a local scale. While knowledge is being gathered in different regions of the world, few results are available from tropical areas. According to Sierra et al. (2007), the estimations of total carbon stocks in tropical forests obtained from aboveground biomass tend to largely underestimate total carbon stocks. An accurate estimation of the magnitude of carbon stocks in the different components of forest ecosystems in tropical climates is therefore essential. More specifically, the estimation of the carbon stored in the aerial and subterranean part of the tree as well as in the fallen leaves and litter, allows one to understand the carbon dynamic and

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Fig. 1. Location of the study sites. All of the experiments were carried out in tropical forest plantations.

the real carbon content on each ecosystem component in detail (Cerri et al., 2003; Fearnside, 1996, 2004; Fearnside and Imbrozio Barbosa, 1998; Sales et al., 2007; Sierra et al., 2007). This fragmented knowledge makes it impossible to obtain more accurate balances for each ecosystem type.

Several methodologies exist to quantify the carbon stocks of the soil and vegetation. Different modelling techniques and methodologies can be used reliably in tropical forest to predict aboveground tree biomass across a broad range of ecosystems (Brown, 2002; Chave et al., 2005). A large number of growth models have already been published by Elfving and Kiviste (1997), Kangur et al. (2007) and Kiviste et al. (2002). Most of these studies have been associated with forestry inventory programs and dasometric studies (Chave et al., 2005; Fearnside and Imbrozio Barbosa, 1998; Montero and Kanninen, 2003; Schulp et al., 2008; Sierra et al., 2007). These works have obtained a partial determination of the carbon content in the ecosystems studied. These authors have only measured the carbon content in a few ecosystem components and the missing information to obtain the total carbon balance was extrapolated or taken from literature. Additionally, in each of these studies there were methodological adaptations and approximations, which in most cases could lead to an erroneous estimation of the potential to capture carbon in forestry ecosystems. Furthermore, due to these data generally being acquired through interpolation, remote sensing or model simulation, sometimes erroneous assessments of carbon stocks in the system exist, associated with non-linear variable estimations, as well as problems with the application of spatial and temporal scales (Kuikman et al., 2003; Paustian et al., 1997). Due to the high variability among tropical plantations in age, genetical factors, management of the commercial plantations and environmental conditions, additional information to improve the total carbon stock estimation in these ecosystems is needed (Sierra et al., 2007).

The aim of this paper is to quantify the effect of: site factors, forest management, environmental conditions and tree species on carbon stocks in mineral soil, forest floor, and tree. At the same time we evaluate the application of forest inventories and soil survey information for carbon stocks inventory improvement. The total carbon stocks in tree, forest floor and mineral topsoil were analyzed in different tropical plantations, i.e. in patula pine (*Pinus patula*) and teak (*Tectona grandis*) stands. In situ observations at a number of test sites in four different zones in Colombia were used for this purpose.

2. Methods

2.1. Site description

For the study of carbon stocks in commercial plantations of Colombia, four different zones were studied. The spatial distribution of the study sites appears in Fig. 1 with their characteristics summarized in Table 1. The sampling zones cover the main Colombian forest types and representative age rank of typical commercial forests. The total area of 3712 ha studied, did not undergo a comprehensive plan for forest management. The study regions are in the Caribbean plains, West and Central Andes. The topography consists of hills and mountains with slopes often higher than 20%, and an altitude ranging from 30 to 2160 m. Soils are deep, with generally low fertility. A description of the complete soil survey can be found in Cortés et al. (1982). The predominant land use is extensive livestock and agriculture (cassava, corn, banana and coffee). Other land uses are natural forests and coal mining.

2.2. Experimental design

The network of plots established covers the main types of planted forest and the age distribution of typical commercial forests in the Andes and the Caribbean regions in Colombia. The monitoring plots were distributed randomly in 54 patula pine plots and 42 teak plots. The dasometric and morphologic characteristics conditions of each individual tree were recorded on each plot of 500 m^2. The carbon stocks in aerial biomass, forest floor, roots and soil profile were measured during a campaign from January to December 2006. To calculate the biomass sampled, an adaptation of Schlegel et al. (2000) methodology was used. The selected trees represent mean characteristics of the population in diameter, height and morphology, all this information is complemented by the annual inventory reports conducted from 1989. The total number of trees per site was set establishing chronosequences with plots, distributed over a wide rank of growth, density and ages.

2.3. Forest components quantification

For the aerial biomass sampled, moist weight in wood, foliage, fruits, fine ($\leq$2.54 cm diameter) and coarse (>2.54 cm diameter) branches were measured in the field. For quantification of the total biomass of the tree, the wood was cut into three pieces and each piece was weighed; afterwards a proportionately distributed, 5 cm thick sample was cut. The total weight of each part of the tree (leaves, branches, trunk and roots) was estimated by measuring the total fresh weight in the field and drying (at 60 °C until constant weight) samples in the laboratory to determine moisture content. Later, a dry biomass subsample was taken for the total carbon content determination according to methodology described by Montané et al. (2006). The total carbon per hectare was determined according to the available information from the forestry inventory of the different studied sites. The carbon content, in proportion