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Carbon stock in rubber tree plantations in Western Ghana and Mato Grosso (Brazil)

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Abstract

Cultivation of rubber trees on non-forested land could act as a carbon sink by sequestering carbon in biomass and indirectly in soils. International political and economical interests, following the Kyoto Protocol, require estimates of this carbon sequestration.

The carbon stock of two rubber tree plantations (*Hevea brasiliensis* (Willd.) Muell.-Arg.) was assessed in two contrasting climatic areas: western region in Ghana (WG; 2–14-year-old) and Mato Grosso (MG; 14–25-year-old) in Brazil.

Trees (76 in WG and 210 in MG) spanning a range of stand ages, clone types and planting layouts were felled and partitioned into log, live lignified branches of selected diameter (large, medium and fine), dead branches, non-lignified fine branches, leaves, taproot and lateral roots. Allometric relationships (log-transformed power functions) based on trunk circumference at a height of 170 cm (C_{170}) were used to predict the tree foliage, aboveground, belowground and total carbon content (kg C tree^{-1}) (r^2 = 0.86–0.99). The way in which carbon content varied as a function of C_{170} depended both on components and sites.

Sampling plots (25 in WG and 34 in MG) were established in stands of varying ages, clones and planting layouts, to quantify carbon pools. The tree carbon stocks (t C ha^{-1}) estimated from the allometric relationships for total tree were fitted as a function of stand age using a non-linear sigmoid curve of Gompertz (total tree r^2 = 0.841 and 0.854 in WG and MG, respectively). Predicted tree carbon stock for 14-year-old stands was 83% higher in WG (76.3 t C ha^{-1}) than in MG (41.7 t C ha^{-1}), which was partially explained by a difference in tree height growth between the two locations resulting from the contrasting sites. In addition to tree components, the carbon stocks associated with dead wood on the ground, understorey vegetation, litter layer, fine roots (0–60 cm), soil organic carbon (0–60 cm) and charcoal (0–60 cm) were assessed using linear mixed models to evaluate the influence of clone, site, planting layout and age. Only age appeared to have a significant effect for some pools.

For 14-year-old stands, the contribution of the soil organic carbon pool (0–60 cm) ranged between 39 and 69% of the total carbon stock, which amounted to 135 and 153 t C ha^{-1}, in WG and MG, respectively. The cumulated contribution of all remaining soil and ground pools (dead wood on the ground, understorey vegetation, litter layer, fine roots and charcoal) was about 5% in both sites.

In the framework of the Kyoto Protocol, these results could be useful when drafting a Project Design Document (PDD) for Afforestation and Reforestation Clean Development Mechanism (AR-CDM).

Keywords: Carbon; Allometric equation; *Hevea brasiliensis*; Site effect; Age effect

1. Introduction

The rubber tree (*Hevea brasiliensis* (Willd.) Muell.-Arg.), of the family Euphorbiaceae, originates from the Amazon basin forest and is now cultivated for latex production in all tropical zones by about 9,675,000 ha (ISRG, 1999).

The growing political (the Kyoto Protocol) and economical interest in carbon accounting requires ways and means of estimating carbon sources and sinks. The biggest carbon source originates from fossil fuel burning and cement production (6.3 Gt C year^{-1}) (Prentice et al., 2001) but emissions from land use change are far from negligible (2.2 Gt C year^{-1}) and mainly result from tropical deforestation (Houghton, 2003). Carbon sinks are associated with CO_2 absorption by the oceans (2.4 Gt C year^{-1}) (Plattner et al., 2002) and terrestrial uptake (3.6 Gt C year^{-1}) (Prentice et al., 2001; Houghton and Goodale, 2004).

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Global (151.2×10^8 ha terrestrial storage area) carbon stocks in terrestrial vegetation (466 Gt C) and in the soil down to a depth of 1 m (2011 Gt C) appear quite limited compared to the 39000 Gt C in oceans and the 75×10^6 Gt C in rocks but are of the same order of magnitude as those stored in the atmosphere (760 Gt C) (Bolin et al., 2000).

The Kyoto protocol requires the rich, industrialized countries of the world, as listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC), to reduce their collective greenhouse gas emissions to at least 5.2% below their 1990 emission levels during the first commitment period (2008–2012). To complete these engagements, in a cost effective way, the Kyoto Protocol (UNFCCC, 1997) establishes flexible market mechanisms. Under the Clean Development Mechanism (CDM), the UNFCCC offers the possibility of enhancing rubber plantation development and participating in the host country's sustainable development. In fact, since rubber tree plantations correspond to the definition of forest, the subsequent carbon sinks resulting from reforestation in degraded regions (outside Parties listed in Annex I) can be eligible as CDM.

Although studies were carried out on carbon sequestration in rubber tree plantations (Yang et al., 2005), none of them simultaneously assessed the complete set of pools – aboveground biomass, belowground biomass, litter, dead wood, soil – necessary to investigate carbon additionality in the context of afforestation and reforestation (AR) activities (GPG LULUCF IPCC, 2004). Many studies estimate tree biomass. Whereas numerous allometric relationships have been developed for aboveground rubber tree parts (Shorrocks et al., 1965; Chaudhuri et al., 1995; Dey et al., 1996; Schroth et al., 2002; Rojo-Martinez et al., 2005; Rodrigo et al., 2005), few data are available for coarse roots; in addition, they usually comprise a limited number of trees. Many other studies (Haag and Guerrini, 1984; Aweto, 1995; Karthikakuttyamma et al., 1998; Mandal et al., 2001; Zhang and Zhang, 2003, 2005; Yang et al., 2004) examined soil organic carbon evolution in rubber fields in comparison with other vegetation types but results were largely affected by previous land use. Some pools such as understorey vegetation and litter were more rarely investigated (Ren et al., 1999; Philip et al., 2003), while others such as fine roots and dead wood have, to our knowledge, never been investigated.

Our study investigates the change in carbon stock with stand age on two contrasting sites, including all the pools needed to be assessed to realize an Afforestation and Reforestation Clean Development Mechanism (AR-CDM).

The influence of age was studied by sampling throughout the range of stand ages in the two rubber plantations—Western Ghana (WG: 2–14 years old) and Mato Grosso Brazil (MG: 14–25 years old).

The influence of site was assessed by comparing plantations from two areas associated with contrasting growth conditions: the WG plantation was located in the biome of the tropical rain forest, while the MG stands were under the savanna biome, more precisely the Cerrado (native dry forest).

2. Materials and methods

2.1. Sites

2.1.1. Western Ghana (WG)

In WG, sampling was carried out in the 11,000 ha of the Ghana Rubber Estate Limited (GREL) plantations next to Agona (4°55′N and 2°02′W). GREL was established from 1962 onwards, along the shore in the vegetation zone of the rain forest in southwestern Ghana characterized by a sub-equatorial climate. The rainfall regime (Fig. 1) is bimodal with four seasons; two rainy seasons: a major in April–July and a minor in October–November, and two dry seasons: a major in December–March and a minor in August–September. Monthly rainfall varies between 0 and 500 mm, while annual rainfall ranges from 1200 to 1800 mm (Fig. 1). Average relative air humidity is between 95 and 100%. Average annual temperature ranges between 24 and 27 °C. Absolute extreme temperatures are 15 and 40 °C. The landscape is undulating with slopes varying from 1 to 30%. The soils developed from the weathering of granite (Atsivor et al., 2001). Acrisols are located on the eroding slopes of low hills while ferralsols are present on nearby stable pediments or uplands (Driessen et al., 2001). Fine earth (<2 mm particle size) is dominated by sand (76%) and clay (22%) while gravel is found at a depth of 10–60 cm. The soils are acid (pH_{H_2O} 4.6) and well drained. The mean soil bulk densities out of stones and its standard deviation is 1.19 ± 0.38 g cm^{-3} ($n = 225$) over a depth of 0–60 cm.

Actual rubber stands are from a second generation of rubber trees.

In this region, most of the land is covered by secondary forest, light bush and oil palm crops. Shifting cultivation (after burning) and mixed cropping dominate.

2.1.2. Mato Grosso (MG)

In MG, sampling took place at the Plantation Edouard Michelin (PEM) next to Itiquira between Campo Grande and Cuiaba (17°21′S and 54°43′W). PEM was established in 1979 and covers 8500 ha. The study area, situated at 500 m elevation, is characterized by a sub-tropical climate type with a dry season lasting 4 months (May 15th–September 15th). Monthly rainfall

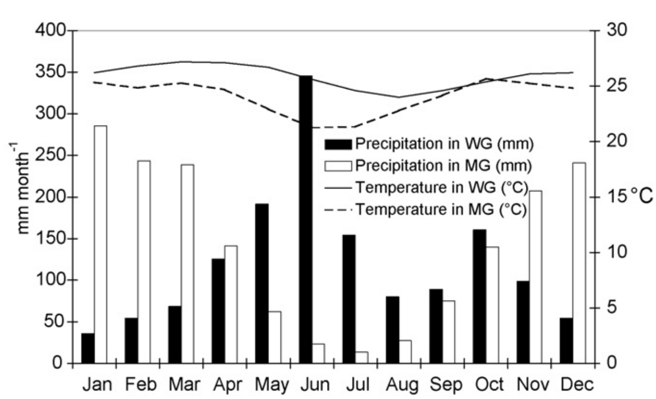

Fig. 1. Mean pattern of the monthly precipitation (mm month^{-1}) and temperature (°C) in Western Ghana (WG) and Mato Grosso (MG) observed over a 24-year period (1979–2003).