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ORIGINAL ARTICLE

Carbon allocation in a Costa Rican dry forest derived from tree ring analysis

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ABSTRACT

The rising discussion on carbon balance of tropical forests often does not consider the sequestration potential of secondary dry forests, which are becoming an increasing importance due to land use change and reforestation. We have developed an easy applicable tool for the estimation of biomass increment of tropical secondary forest stands on the base of tree ring analysis. The existence of annual rings was shown by a combination of anatomical examination and radiocarbon estimations. With tree ring analysis, forest inventories and destructive sampling the above-ground biomass increment of secondary forest stands of age between 9 and 48 years in the dry forest region of Guanacaste, Costa Rica were estimated. The above-ground biomass increment of the tree layer varies between 2.4 and 3.2 Mg/ha yr in different stands. Lianas contribute with up to 23% additional production. Differences in productivity among the stands along a chronosequence were not significant. The measured carbon allocation potential of 1.7–2.1 Mg C/ha yr lies in the range of reported values from other tropical dry forests and old growth humid forests as well.

Introduction

The carbon cycle in tropical forests is the objective of numerous studies and publications with the main focus on humid, lowland and old growth forests, which may act as carbon sinks (Malhi et al., 2004; Lewis et al., 2009). Little attention, however, is paid to the carbon sequestration potential of tropical dry forests, even though this biome covers almost half of the land mass in the tropics (Murphy and Lugo, 1986). In the past dry forests were under high settlement pressure due to their favorable living conditions in comparison to tropical humid climates. This has led to severe deforestation and conversion to agriculture in Latin America. In the last decade severe changes of economic conditions generated land use change into two directions. Decreasing prices of beef and other traditional agricultural products (e.g. sisal in Yucatan) had the consequence that many farms were abandoned followed by reforestation with secondary vegetation (Sanchez-Azofeifa et al., 2005). On the other hand the rapid expansion of soy-beans and other crops for animal feed and recently for biofuels caused increasing deforestation rates in dry forest areas particularly in Brazil (Soares-Filho et al., 2006).

A major driving factor for the increased production of biofuels is the hope of reducing greenhouse gas emission. The reduction potential of many bioenergy crops however is rather low, in particular if environmental impacts of land use change are included in a carbon balance (Scharlemann and Laurance, 2008). One compartment of this balance is the allocation of carbon in secondary vegetation as in the dry forest region of Costa Rica.

The estimation of carbon sequestration of natural tropical forests is based on several approaches. In old growth forests repeated diameter measurements and allometric biomass calculations are used to estimate productivity. This method often suffers from a short measurement period, which results in an underestimation of the long term growth rates (Brienen, 2005). In young secondary vegetation the above ground biomass can be harvested but an often unsolved question then is the exact age determination of the investigated stand. Brienen et al. (2009) showed in a secondary forest in southern Mexico that counting tree rings and comparing the results with local farmer recollections have the potential to solve this problem. We used two different approaches to proof the annual nature of tree rings: anatomical studies of the cambial zone as a very traditional technique (Coster, 1927) and modern radiocarbon estimations (Worbes and Junk, 1989). On this base we want to use tree ring analysis for an applied research question and estimate the potential for carbon sequestration by tropical dry forests. On this basis tree ring analysis in combination with forest inventory, destructive sampling and wood anatomy have been used to derive growth rate increment of most species and estimate the potential of tropical dry forests in Costa Rica for carbon sequestration.

Sites, material and methods

The research area is located at the Hacienda Cerbastán (10°49′N, 85°15′W), 9 km north west of Cañas in the province Guanacaste,

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Table 1
Structural features of the selected stands. Above-ground biomass for all stands on the base of allometric calculations.

Stand no.	1	2	3	4	5
Geographical position	10°51′655 N 85°15′652 W	10°51′787 N 85°15′953 W	10°51′775 N 85°13′937 W	10°51′285 N 85°15′805 W	10°49′654 N 85°15′502 W
Dominant species	*Lonchocarpus minimiflorus*	*Cochlospermum vitifolium*	*Lonchocarpus minimiflorus*	*Stemmadenia obovata*	*Luehea candida & speciosa*
Minimal stand age (yr)	9	14	15	48	47
Mean stand age (yr)	7.88	9.07	9.05	17.55	19.37
Maximum height (m)	8	10	10	14	20
Mean height (m)	5.34	6.34	6.01	8.5	8.16
Basal area (m^2)	3.05	8.38	10.03	13.25	17.60
Wood density (g/cm)	0.78 ± 0.08	0.68 ± 0.20	0.68 ± 0.10	0.70 ± 0.19	0.67 ± 0.16
Density stems/ha >5 cm	210	690	800	410	920
Population density/ha 1–4.9 cm	3205	8750	9775	3385	2450
AGB >5 cm (Mg/ha)	2.71	10.09	18.39	43.8	59.12
Total AGB (Mg/ha)	19.43	21.88	29.23	44.39	59.87

Costa Rica. The climate is strongly seasonal with a mean annual precipitation of about 1400 mm. The dry period lasts from January until March or April with little or no rainfall in these months.

At five locations research plots were chosen for vegetation analysis in secondary stands of different successional development. Three plots (Nos. 1–3) were located on abandoned pastures with relatively young woody vegetation while the stands at plots 4 and 5 show a well developed tree layer indicating greater stand age than the three others. Further characteristics of the stands are given in Table 1. The field work was performed between April 2001 and July 2002. The species names follow the International Plant Names Index (formerly Index Kewensis).

At all sites inventory plots of 1000 m^2 (40 × 25) each were installed. In three subplots of 10 × 10 m all individuals above 1 cm DBH were inventoried and their relative position within the plot determined. The height of the individuals up to 12 m was measured with a telescope measuring stick and above 12 m trigonometric calculation and a clinometer were used. The diameter was measured at breast height with a diameter measuring tape. Complete destructive biomass estimations including resprouting and lianas were carried out in the subplots each of the plots 1–3. In these biomass subplots all trees and all lianas were harvested and the fresh woody biomass was weighted. Samples were taken to the laboratory and dried to measure water content, volume and specific gravity to calculate the woody dry biomass. The allometric above ground biomass (AGB) estimation is based on the traditional and in forestry literature often used equation from Cannel (1984):

$$AGB = F \times p \times h \times p \times (d/2)^2$$

with a conservative form factor of 0.6 (F), specific gravity of the wood (p), the height of the trees (h) and the diameter in breast height (d). The specific gravity was estimated from the dry weight and the volume of wood samples (see below).

The annual biomass production was calculated from biomass divided by the age of the trees derived from tree rings. For the tree ring analyses stem discs were taken in the biomass plots from all individuals with a DBH above 5 cm and from 3–7 individuals of each species with a diameter between 1 cm and 5 cm. In plots 4 and 5 every tree with a diameter at breast height above 5 cm was cored with an increment corer. The samples were shipped to Germany and treated in the tree ring laboratory of the University of Göttingen as follows: cores were glued onto a wooden support and polished – as were the stem discs from the sites 1–3 – with sandpaper up to a grid of 600 to increase the visibility of the growth zones. Tree ring analysis was carried out with a binocular microscope at 40× magnification.

The structure of the growth zones was identified according to the classification scheme of Worbes (1989) enabling the definition of the growth zone boundaries. The distinctiveness was classified subjectively from very distinct to indistinct as shown in Table 2.

The radiocarbon test to show the existence of annual rings was carried out with stem discs from the leaf shedding, stem succulent species *Bursera simaruba* and from *Swietenia macrophylla*, which is classified as evergreen. The *Bursera* tree was felled in 2001, the *Swietenia* stem was found at a log storage at the Hacienda La Pacifica in 1999, its exact felling date was unclear but according to the managers of the Hacienda not earlier than 1997. The dating analysis is based on the nuclear bomb effect, described in detail in Worbes and Junk (1989). Individual growth zones were isolated, in the case of *Swietenia* in defined distances from each other. Starting from the outside to the center the first ring was taken 17 rings from the bark, the next 10 from this, then 6, then 12 and again 12 rings apart from the previous. In the case of *Bursera* the rings were predated by counting the rings back from the bark to the years 1995 and 1982. Their radiocarbon ($\delta^{14}C$) content was measured at the Isotope Laboratory of the University of Göttingen in February 2001 for the three youngest rings and for the others at the Institute of Physics, University of Erlangen. The results were compared with the radiocarbon content of the Atmosphere of the Northern hemisphere at low latitudes (Hua et al., 1999).

For the test of the cambial activity samples from seven species were taken with an increment corer at breast height from one to five individuals from March 1999 until January 2000. The samples were fixed with Polyethylene glycol 1500. Later anatomical slides were produced in the Wood Anatomical Laboratory of the Institute for Wood Biology of the former Bundesforschungsanstalt für Forst- und Holzwirtschaft in Hamburg. Anatomical sections were stained with Astra Blue and Safranine. With a microscope and a digital camera images were taken and the developmental stage of the cambium was evaluated qualitatively. We classified the cambium as dormant when a sharp boundary between latewood cells and cambial zone was visible (Fig. 2), while the presence of a differentiating zone (Fig. 2) indicated an active cambium.

Results

Distinctiveness of growth zones

The majority of the investigated 45 species shows more or less distinct growth zones even in the small core samples permitting an age determination in most cases (Fig. 1). In some species with indistinct rings in the core samples, differentiation was easier in disc samples (e.g. *Semialarium mexicanum*) and aided the final definition of tree ring boundaries. Only six species showed very indistinct rings in all samples (Table 1). There was no general trend between anatomical features (the type of growth zone