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ABOVEGROUND STOCK OF BIOMASS AND ORGANIC CARBON IN STANDS OF *Pinus taeda* L.

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ABSTRACT: This study aimed to estimate biomass and organic carbon in stands of *Pinus taeda* L. at different ages (14, 16, 19, 21, 22, 23 and 32 years) and located in the municipality of General Carneiro (PR). In order to estimate biomass and organic carbon in different tree components (needles, live branches, dead branches, bark and stem wood), the destructive quantification method was used in which seven trees from each age category were randomly sampled across the stand. Stocks of biomass and organic carbon were found to vary between the different age categories, mainly as a result of existing dissimilarities between ages in association with forest management practices such as thinning, pruning and tree density per hectare.

Key words: Nonnative forests, sustainability, forest stand.

BIOMASSA E CARBONO ORGÂNICO ACIMA DO SOLO EM PLANTIOS DE *Pinus taeda* L.

RESUMO: Objetivou-se estimar a biomassa e carbono orgânico em plantios de *Pinus taeda* L. com diferentes idades (14, 16, 19, 21, 22, 23 e 32 anos), localizados no município de General Carneiro, PR. Para estimar a biomassa e o carbono orgânico nos diferentes componentes das árvores (acículas, galhos vivos, galhos mortos, casca e madeira do fuste) foi utilizado o método destrutivo de quantificação, utilizando-se para tanto a amostragem de sete árvores distribuídas aleatoriamente pelo plantio em cada uma das idades. O estoque de biomassa e carbono orgânico nas diferentes idades consideradas variou, principalmente, em função das diferenças existentes entre as idades, também relacionadas às condições de manejo, como desbastes, desramas e densidade de indivíduos por hectare.

Palavras-chave: Florestas plantadas, sustentabilidade, plantio florestal.

1 INTRODUCTION

The correlation between concentrations of carbon dioxide (CO₂) in the atmosphere and increasing average temperatures on the planet (TANS; KEELING, 2012) is giving serious cause for concerns over the impact of increasing levels of greenhouse gases (GHG) on worldwide climate (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - IPCC, 2011). There has also been a growing interest in studies exploring the ability of nonnative forests to remove CO₂ from the atmosphere and to store carbon in their biomass, on account of their fast-growing rates and resulting ability to withdraw atmospheric carbon.

Examples of the above are the forest stands of *Pinus taeda* L. in southern Brazil, which are fast-growing crops that have been supplying raw material to forest-based industries. And therefore, owing to their rapid growth and the resulting larger quantity of organic carbon they store, quantifying tree biomass and organic carbon stocks in such crops have become a necessity.

The amount of carbon stocked in forest stands can be estimated by quantifying the existing biomass and subsequently determining the carbon concentration. This determination can be done either by using the direct method in which trees are felled, dismembered and the resulting components are weighed (SANQUETTA; BALBINOT, 2004), or by the indirect method in which allometric equations are used adopting biomass factors (BREUGEL et al., 2011; SEGURA; KANNINEN, 2005; SOMOGYI et al., 2006).

The biomass accumulated in different ecosystems is affected by all factors related to photosynthesis and respiration (KOZLOWSKI; PALLARDY, 1996). Biomass accumulation and tree growth are dependent, among other things, on site quality, soil texture, nutrient availability, climate characteristics and local altitude (KADEBA, 1994) as well as on originating place (CALDEIRA et al., 2000, 2001, 2011).

The correlation of biomass with primary productivity is usually low in young, fast-growing stands and higher where most of the energy is used for

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maintaining existing high biomass stocks. This indicates that biomass and carbon stocks will vary according to the growth stage of the crop (CALDEIRA et al., 2011; LUGO et al., 1988; WATZLAWICK et al., 2002). Accordingly, the objective of this study is to estimate biomass and organic carbon in stands of *Pinus taeda* L. at different ages and spacing densities.

2 MATERIAL AND METHODS

2.1 Study site

The experimental study was conducted in the municipality of General Carneiro, Paraná (Figure 1), which is located at the intersection of geographical coordinates 26° 43' 00" (S) and 51° 24' 35" (W), at an average altitude of 1,000 m (PARANÁ, 1987). The rural estate in which the experiment took place is around 4,570 ha in area.

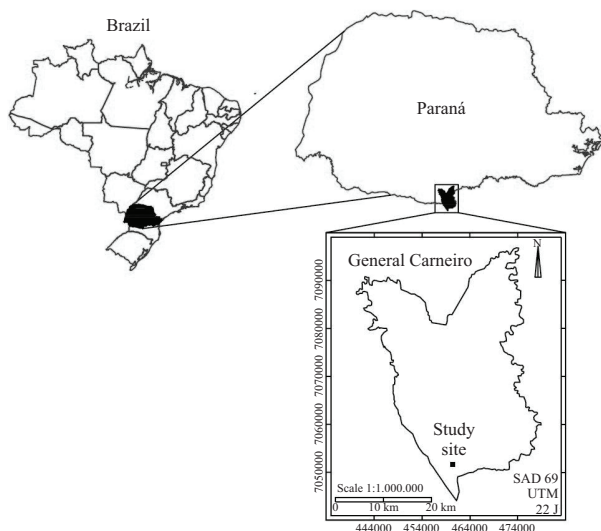


Figure 1 – Location of the study site.

Figura 1 – Localização da área de estudo.

The local climate, according to Köppen classification, is humid subtropical (Cfb), that is, temperate with cool summers and with severe frosts in the winter, with no dry season. The average temperature is below 22° C in the warmest month and below 18° C in the coldest month, and average annual rainfall is between 1,600-1,800 mm (CAVIGLIONE et al., 2012). And the local soils are predominantly the litholic neosol, cambisol and argisol types, according to the classification system defined by the Brazilian agricultural research enterprise Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (2006).

According to the classification system defined by the Brazilian institute of geography and statistics Instituto Brasileiro de Geografia e Estatística - IBGE (1992), the original forest formation of the study site is the araucaria moist forest type. Due to anthropic activity, however, the local vegetation is currently at different successional stages.

2.2 Field and laboratory procedures

Biomass data were collected in the field by using the destructive quantification method, defining seven sampling units (SU) 8 x 8 m in size (64 m²), one for each age category, each age with a different spacing density (Table 1). All trees were felled within each SU and the following dendrometric variables were obtained: diameter at breast height (DAP), total height (Ht) and commercial height (Hc). With these variables, volume (V) was computed, expressed in m³.ha⁻¹, along with basal area (G), expressed in m².ha⁻¹.

After trees were felled in each sampling unit, they were dismembered and each component was then weighed and sampled. The dismembering process consisted of removing needles from branches, then separating live branches from dead branches, and finally cutting the stem into log sections for subsequent weighing with a Lider PR30 spring scale with a load capacity of 500 kg (500 g minimum, ±100 g error).

All tree components were sampled. Leaf sampling consisted of removing needles from the lower, mid and upper portions of the tree crown. The same procedure was used for the branches, removing samples with bark from the extremity and mid portions. As for stem and bark, discs were removed from the portions 0.5 m above the ground and 0.5 m below the top extremity and from the mid portion of the stem.

The total weight of stem, live branches, dead branches and needles was determined in the field, while the total weight of bark was determined using bark factor ratios, based on the thickness of the bark in the three stem portions being sampled.

The field samples were weighed in a laboratory using a digital scale (± 0.1 g error). Following the weighing procedure, the samples were placed in a forced-air oven at a constant temperature of 65° C until they reached a constant weight, prior to determining the dry weight and conducting a chemical analysis of organic carbon levels.

Analyses of organic carbon levels for each tree component were conducted in the Laboratory of Forest Ecology, Federal University of Santa Maria, according to the methodology proposed by Tedesco et al. (1995).

Table 1 – Dendrometric data of *Pinus taeda* stands at different ages.**Tabela 1** – Informações dendrométricas das plantações de *Pinus taeda* nas diferentes idades.

Age	No. of trees/ha ⁻¹	DAP (cm)	Ht (m)	G (m ² ha ⁻¹)	V (m ³ ha ⁻¹)
14	898	27.93	20.1	40.28	406.65
16	812	27.48	21.4	27.81	297.91
19	100	37.88	24.6	17.61	216.23
21	440	31.87	26.3	49.91	655.46
22	398	35.33	23.5	47.92	569.91
23	200	43.77	24.9	47.40	594.56
32	100	47.43	24.9	27.60	342.44
mean	402	33.36	23.3	40.44	477.76
standard deviation	198.81	7.58	2.39	15.32	206.98
IC*	402 ± 279.6	33.36 ± 5.18	23.3 ± 1.63	40.44 ± 10.47	477.76 ± 141.39

DAP = diameter at breast height; Ht = total height; G = basal area; V = volume outside bark. *Confidence interval at the 99% probability level.

The data processing stage included calculations of fresh biomass, dry biomass and organic carbon. With the data on green biomass and moisture content of each component of each felled tree, dry biomass was derived using the following formula:

$$BS = BV \times \left(1 - \frac{Um}{100}\right)$$

where:

BS = dry biomass (kg);

BV = green biomass (kg);

Um = moisture content (%).

With the data on dry biomass, organic carbon levels were quantified in each tree component using the following formula:

$$CO = BS \times \left(\frac{TCO}{100}\right)$$

where:

CO = organic carbon (kg);

BS = dry biomass (kg);

TCO = average organic carbon levels (%).

3 RESULTS AND DISCUSSION

The inventory of the *Pinus taeda* stand itemized seven different tree ages, 14, 16, 19, 21, 22, 23 and 32 years, with densities of 898, 812, 100, 440, 398, 200 and 100 trees per hectare (trees.ha⁻¹) respectively (Table 1).

Different densities are a function of various thinning regimes, whereby the 32-, 23- and 22-year-old stands were thinned four times, while the 21-, 19- and 16-year-old stands were thinned three times, and the 14-year-old stand was thinned once only.

A higher biomass yield and organic carbon stock was found in the 21-year-old stand, 273.34 Mg.ha⁻¹ and 114.49 Mg.ha⁻¹ respectively (Table 2), as the stand at this age had greater basal area and wood productivity, 49.91 m².ha⁻¹ and 655.46 m³.ha⁻¹. The 14-year-old and the 32-year-old stands had similar total biomass and carbon accumulation, noting that tree density per hectare directly influenced the amount of biomass and carbon stocked. The 19-year-old stand had 90.58 Mg.ha⁻¹ and 38.01 Mg.ha⁻¹ (100 trees.ha⁻¹) respectively of biomass and carbon stock. When studying the same species at age 5 years (1,600 trees.ha⁻¹) in Cambará do Sul (RS), Balbinot et al. (2003) found 33.2 Mg.ha⁻¹ of biomass and 15.3 Mg.ha⁻¹ of carbon stock, noting that the actual values found in each study did differ, though the variation is insubstantial if one considers the age difference between the stands (14 years). In young stands yet with high tree density, carbon stocks could be similar or even higher than in older stands with low tree density (Tables 1 and 2).

Schumacher et al. (2002b) quantified biomass and carbon stock for a *Pinus taeda* crop with trees at different ages (5, 10, 15 and 20 years) in Cambará do Sul (RS) and found respectively 264.00 Mg.ha⁻¹ and 115.81 Mg.ha⁻¹ of biomass and carbon accumulated for age 20 years, based

Table 2 – Biomass and organic carbon (Mg ha⁻¹) in *Pinus taeda* stands.**Tabela 2** – Biomassa e carbono orgânico (Mg ha⁻¹) em plantios de *Pinus taeda*.

Age (years)	Biomass					Total
	Needles	Live Branches	Dead Branches	Bark	Stem Wood	
14	5.62	23.57	4.40	19.29	95.33	148.21
16	5.62	10.44	3.75	9.63	79.50	108.94
19	3.68	11.56	4.03	9.07	62.24	90.58
21	8.06	34.48	10.23	33.27	187.30	273.34
22	9.11	31.41	9.94	32.06	149.86	232.38
23	9.69	47.30	12.53	32.27	155.62	257.41
32	8.18	21.18	4.46	20.42	99.33	153.57
\bar{x} (mean)	7.14	25.71	7.05	22.29	118.45	180.63
S (standard deviation)	2.19	13.13	3.70	10.51	45.98	73.26
IC*	7.14 ± 3.07	25.71 ± 18.40	7.05 ± 5.18	22.29 ± 14.73	118.45 ± 64.42	180.63 ± 102.65

Age (years)	Organic carbon					Total
	Needles	Live Branches	Dead Branches	Bark	Stem Wood	
14	2.36	9.62	1.80	7.41	40.75	61.94
16	2.36	4.26	1.54	3.70	33.98	45.84
19	1.55	4.72	1.65	3.48	26.61	38.01
21	3.38	14.08	4.18	12.78	80.07	114.49
22	3.82	12.82	4.06	12.31	64.06	97.09
23	4.07	19.31	5.12	12.39	66.53	107.42
32	3.43	8.65	1.82	7.84	42.46	64.21
\bar{x} (mean)	3.00	10.49	2.88	8.56	50.64	75.57
S (standard deviation)	0.92	5.36	1.51	4.04	19.66	30.56
IC*	3.00 ± 1.29	10.49 ± 7.51	2.88 ± 2.12	8.56 ± 5.66	50.64 ± 27.55	75.57 ± 42.82

*Confidence interval at the 99% probability level.

on tree density of 300 trees.ha⁻¹. These values are similar to results found in this work for age 21, despite more plants per hectare. Balbinot et al. (2008) studied *Pinus* spp. at different ages (under 5, 5 to 15 and above 15 years old) in southern Paraná and found 198.46 Mg.ha⁻¹ and 89.44 Mg.ha⁻¹ (689 trees.ha⁻¹) of biomass and carbon respectively in stands over 15 years old.

The biomass yield found here for 14-year-old *Pinus taeda* (148.21 Mg.ha⁻¹) differed from value found by Valeri et al. (1989) (183.9 Mg.ha⁻¹) in the region of Telêmaco Borba (PR). Despite stands being even-aged, the density of trees and number of thinnings differed, with three thinnings in the case of Valeri et al. (1989) yet with less intensity. This

study had fewer plants per hectare. Valeri et al. (1989) found the following biomass values distributed across plant compartments: 9.4 Mg ha⁻¹ in needles, 26.3 Mg ha⁻¹ in branches, 1.8 Mg ha⁻¹ in shoot, 11.5 Mg ha⁻¹ in bark and 134.9 Mg ha⁻¹ in wood. Shoot is defined as the portion of stem with bark where diameter is 2.5 to 7.0 cm. Where diameter is less than above specified, the portion is defined as branch.

In a study conducted with *Pinus taeda* at age 18 years in Cambará do Sul (RS), Schumacher et al. (2002a) found a total aboveground biomass of 151.54 Mg.ha⁻¹ adopting a density of 291 trees.ha⁻¹, against a density of 100 trees.ha⁻¹ in this study at age 19 years, the difference owing to plant density.

In comparing the biomass and carbon levels found for different ages, the 19-year-old stand had lower tree biomass yield than the younger 14- and 16-year-old stands. This fact can be explained by the low tree density and consequently lower biomass yield. Melo et al. (2004) argue that different management regimes, with different interventions and number of trees being removed, do affect the amount of carbon stocked in a given planning horizon.

Alemdag and Stiell (1982), when studying 17-year-old stands of *Pinus resinosa* with spacings of 1.52 x 1.52 m and 4.27 x 4.27 m, found a total aboveground biomass of 190.6 Mg.ha⁻¹ in the denser stand, against 98.2 Mg.ha⁻¹ in the sparser stand. Consequently, the biomass of wood (stem wood), bark, dead branches and live branches with needles also decreased with increasing tree spacing.

The needle biomass of *Pinus taeda* tends to remain constant with increasing age, and as a result the amounts of biomass and carbon also follow suit. A study conducted by Heep and Brister (1982) with *Pinus taeda* stands at 10 to 27 years old revealed that the needle biomass remained constant with increasing age. Likewise, Valeri et al. (1989) found, when studying *Pinus taeda* stands at 7 (9.434 Mg.ha⁻¹), 10 (9.665 Mg.ha⁻¹) and 14 years old (9.338 Mg.ha⁻¹), that the needle biomass was virtually the same in all three stand ages.

Regardless of age, the largest contribution of aboveground biomass and organic carbon came from the component stem wood. Sequence patterns were found to differ regarding the contribution of tree biomass. A similar result was observed by Schumacher et al. (2002b) for *Pinus taeda* stands at 15 and 20 years old. In descending order, contributions came from stem > branches > bark > needles, though at 10 years old the sequence was stem > needles > branches > bark. Schumacher et al. (2002a), studying the same species at 18 years old, observed the sequence stem > live branches > bark > needles > dead branches. Typically, aboveground biomass is distributed in the order wood > branches > bark > leaves (CURLIN, 1970). Variations in biomass distribution across different plant organs differ from one species to another and even within the same species (ABRAHAMSON; GADGIL, 1973).

A larger contribution from stem wood relative to other tree components was also observed in other studies, including Valeri et al. (1989) with *Pinus taeda* at 7, 10 and 14 years old, and Caldeira et al. (2000) with *Acacia mearnsii* at 2 and 4 years old. Madgwick and Kreh (1980) quantified biomass yield in ten stands of *Pinus taeda* at

different ages and found that the biomass of live branches decreased with increasing site density while the biomass of needles increased with increasing site density and quality. In the study in question, however, such correlation was not observed whether for the biomass of live or of dead branches, possibly influenced by natural pruning or by management practices in the relevant areas. In their works, however, Schumacher et al. (2002a, 2002b) observed a certain tendency of branch biomass to increase with age.

Therefore, it became clear that the differences found in biomass yield and organic carbon levels for the species in question are affected not only by the abovementioned factors but also by basal area, volume, number of trees per hectare and site, all of which directly influencing tree biomass and organic carbon stock. Madgwick and Kreh (1980) argue that stem biomass increases proportionally with increases in cylindrical volume, that is, basal area x height (m³.ha⁻¹).

Overall, in comparing the biomass found in different tree components in this study with other studies on the same species, values were found to be dissimilar from the findings of Schumacher et al. (2002a, 2002b) and Valeri et al. (1989). Probably, several factors are accountable, including environmental factors and plant-related factors (SPURR; BARNES, 1986), soil and climate conditions (HAAG, 1985), age (CROMER et al., 1975; VALERI et al., 1989) and plant density (VALERI et al. 1989).

As is known, Brazil's largest existing forested areas are owned by companies that have well defined economic activities. As a result, the management regimes being applied to the crops are designed to suit company-specific purposes. Therefore, with the possibility of trading carbon credits also comes the need to define both the best way to attain that and also its duration horizon (SANQUETTA et al., 2004).

4 CONCLUSIONS

The biomass and organic carbon stocks found in this study for *Pinus taeda* at various ages ranged respectively from 90.58 Mg.ha⁻¹ to 273.34 Mg.ha⁻¹ and from 38.01 Mg.ha⁻¹ to 114.49 Mg.ha⁻¹. It was clear that plant density and thinning intensity directly influenced the stocked biomass and carbon.

Different levels of intervention did affect biomass stock, therefore where stands of *Pinus taeda* are intended to integrate carbon credit projects, management practices should analyze the available options taking into account this ecological aspect (environmental service).

As far as preparing a carbon forest project is concerned, it is important to clearly define the intended purpose of the raw material, thoughtfully considering what the best management practice is in order to derive quality raw material and what management practice will result in higher carbon stocks.

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