

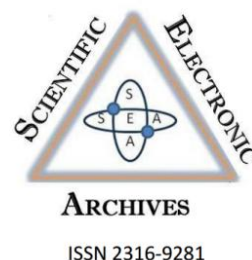
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Basic density and CO₂ sequestration in seven species from the Commemorative Arboretum of 500 Years of Brazil in Alberto Löffgren State Park, São Paulo

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Abstract: Carbon sequestration involves the removal of CO₂ from the atmosphere, aiming to reduce the greenhouse effect. Wood basic density is a direct part of this process. We selected five trees in each of the following species to determine wood basic density and quantify carbon, both sequestered and fixed, for 10 years: *Alchornea sidifolia*, *Ceiba speciosa*, *Gallesia integrifolia*, *Guazuma ulmifolia*, *Inga marginata*, *Maclura tinctoria*, and *Prunus cerasoides*. The study was conducted in the Commemorative Arboretum of 500 Years of Brazil in Alberto Löffgren State Park, São Paulo. Using maximum moisture content capture of CO₂, we studied variations of wood density and CO₂, both fixed and sequestered, by an individual tree in the same species and between species. Values of fixed and sequestered CO₂ showed variations among species with a high dependence on wood density such that trees with higher amounts of CO₂, both fixed and sequestered, were also trees that showed the highest increment both in height and diameter (DBH). Based on these metrics, *G. ulmifolia*, *I. marginata*, *M. tinctoria*, and *P. cerasoides* showed the most potential to sequester carbon. Our calculations showed that planting these four species would result in the sequestration of around 30 tons of carbon per hectare.

Keywords: carbon sequestration, climate change, global warming, wood basic density

Introduction

The incidence of pollutants emitted into the air has risen steadily in the last few decades, and all countries are contributors. Carbon dioxide (CO₂) gas, one of the compounds released into the atmosphere by man, is produced in all parts of the planet, mainly by burning petroleum-derived fuels and by producing cement (75% of total emissions). However, land use processes, especially deforestation and burning, are responsible for a large part of the remaining 25% (C&T Brasil, 2006).

CO₂ is one of the greenhouse gases by the absorption of thermal infrared light. Carbon becomes available to living beings through plants by photosynthesis, and because carbon is stored, it is often called fixed carbon. Biological decomposition is one of the ways in which this process is reversed, releasing CO₂ into the atmosphere. Anthropogenic

activities have generated a considerable increase in CO₂ concentration in the air. In view of the increase in CO₂ emissions, which have intensified the greenhouse effect, likely accounting for a significant increase in temperature on the planet, governments have debated ways to minimize these emissions without harming economic growth. Some initiatives are based on reducing emissions, acquiring carbon credits, implementing projects based on clean technologies in other countries, and planting more trees in order to absorb CO₂ emissions. The Clean Development Mechanism (CDM) was created at the Kyoto Conference as an instrument by which developed countries could invest in projects to promote carbon sequestration and thus reduce CO₂ emissions (Barreto et al., 2009).

The concept of carbon sequestration was enshrined in the 1997 Kyoto Conference with the

purpose of containing and reversing CO₂ accumulation in the atmosphere and, hence, reduce the greenhouse effect. The conservation of carbon stocks in soils, forests and other vegetation types; preservation of native forests; implantation of forests and agroforestry systems and recovery of degraded areas are some methods that can contribute to the reduction of CO₂ concentration in the atmosphere (Environment Brazil, 2010).

The mass of carbon contained in trees is governed by the volume and density of the wood (Phillips et al., 2019). This means that wood density can be used to quantify the amount of carbon in trees. In addition, results of carbon sequestration can be quantified by estimating plant biomass above and below ground, calculating the carbon stored in wood products and the amount of CO₂ absorbed in the photosynthesis process. The study of energy balance and carbon cycle in the atmosphere depends on the quantification of plant biomass in each of the following components of vegetation: aerial part, roots, and layers decomposed on the soil (Ambiente Brasil, 2010).

The sequestration of forest carbon is a viable alternative to mitigate the rise in global temperature. Vegetables, using their photosynthetic capacity, fix atmospheric CO₂, biosynthesizing in the form of carbohydrates and, finally, depositing on the cell wall (Renner, 2004).

According to Baird (2002), CO₂ can be removed from the atmosphere through the selection of plants grown especially for this purpose. Fast growth correlates with faster CO₂ absorption as a result of vigorous tree growth in the tropics. Indeed, one hectare of this type of forest can sequester much more carbon than one hectare of temperate forest (Renner, 2004).

Referring to the Climate Convention, Yu (2004) stated that carbon sequestration is a palliative and not a permanent measure, although it can bring secondary ecological benefits. Variation in the cost of CO₂ absorption is associated with

several factors, such as regional differences in climate, existing variations in soil quality, differences in management, time for cutting and technologies used.

Brazil has the largest plant biodiversity on the planet with more than 55 thousand species of superior plants and about 10 thousand species of bryophytes, fungi and algae, a total equivalent to almost 25% of all existing species of plants (Brazil RU, 2010). However, of all these species, it is not known which species best contribute to CO₂ sequestration.

Considering the importance of studies on CO₂ sequestration of tree species, we selected seven 10-year-old species, six native and one exotic, for our study. Our goal was to determine the effect of basic density on the amount of carbon sequestered these trees planted in an arboretum.

Materials and Methods

Sampling

Alberto Löffgren State Park (PEAL, Portuguese) is located in the northern area of São Paulo City, São Paulo State, Brazil (23°47'S, 46°38'W, elevation 814 m). Climate is Cwa in the Köppen classification, mesothermal and humid with rainy summers and dry winters (Rossi et al., 2009). Ombrophilous Dense Forest is the main vegetation formation of PEAL; anthropic areas are also found with arborets of one or more species (Arzolla et al., 2009). The trees investigated in this study are located in one of these arborets, denominated Commemorative Arboretum of 500 Years of Brazil. In 2000, 24 native species and other exotic species were planted at the site with 4 x 5 m spacing, occupying an area of one hectare (Bonucci et al., 2007).

In the present study, we selected *Alchornea sidifolia*, *Ceiba speciosa*, *Galesia integrifolia*, *Guazuma ulmifolia*, *Inga marginata*, *Maclura tinctoria*, and *Prunus cerasoides*, all 10 years old.

Table 1. Mean dendrometric data of seven 10-year-old species planted in the Commemorative Arboretum of 500 Years of Brazil. Height (m) and DBH = diameter at breast height (cm).

<i>Alchornea sidifolia</i>		<i>Ceiba speciosa</i>		<i>Galesia integrifolia</i>		<i>Guazuma ulmifolia</i>		<i>Inga marginata</i>		<i>Maclura tinctoria</i>		<i>Prunus cerasoides</i>	
Height	DBH	Height	DBH	Height	DBH	Height	DBH	Height	DBH	Height	DBH	Height	DBH
11.2	30	12.1	26.2	12.5	26	15	29	17.1	25.6	12.5	21.8	12.2	25.5

Basic wood density

Basic density was determined by the maximum moisture content method reported in NBR 11941 (ABNT, 2003) and calculated as

$$\rho_{bas} = \frac{1}{\left(\frac{m1}{m2}\right) - 0.346} \quad \text{Eq. 1}$$

where ρ_{bas} = basic wood density (in g.cm⁻³), $m1$ = wet mass, and $m2$ = kiln-dried mass at (105 ± 2) °C.

CO₂ sequestration

After collecting the samples, the following procedures were performed by tree and species, according to Bucci et al. (2010): Calculation of trunk volume or bole volume as

$$Tv = \frac{\pi}{4 \times DBH^2 \times H \times 0.5} \quad \text{Eq. 2}$$

where Tv = trunk volume (in m³), DBH = diameter at breast height, and H = tree height saturated volume.

Calculation of branch and root volume depends on such factors as species, age, and location. In this case, we estimated 25% (1.25) over the trunk volume and calculated the total volume as

$$1.25 \times Tv \text{ (m}^3\text{)} \quad \text{Eq. 3}$$

We calculated weight (W, in kg) as

$$W = \rho_{bas} \times Tv \times 1000 \quad \text{Eq. 4}$$

Basic density is the relationship between absolutely dry mass and saturated volume of wood, as described in the previous item. Then, to calculate fixed carbon, we applied a factor of 0.5 to tree weight, considering that 50% of the wood consists of carbon with the remainder constituted mainly by water and nutrients. We calculated absorbed CO₂ by multiplying the fixed carbon content by 3.67, as obtained from CO₂ / C, or a ratio of 44/12.

Data analyses

We undertook a parametric analysis of variance (one-way analysis of variance-ANOVA). When a significant difference was observed, Tukey's test was used to identify pairs of significantly different means between species.

Results and discussion

We observed variations in basic density relative to both fixed and sequestered CO₂ among seven studied species. Basic density was higher in *G. ulmifolia*, *I. marginata*, *M. tinctoria*, and *P. cerasoides* (Figure 1a). Fixed and sequestered CO₂ values oscillated, but we observed higher values in *G. ulmifolia* and *I. marginata*, but lower values in *C. speciosa* (Figure 1b).

Table 2 shows total values of fixed and sequestered CO₂ per hectare (ha) of each species according to tree number. *Guazuma ulmifolia* and *I. marginata* showed higher carbon sequestration capacity (Table 2 and Figure 1b), followed by *M. tinctoria* and *P. cerasoides*. *Ceiba speciosa* was the species with the lowest potential. According to the results in an area of one hectare with these species and number of trees of each species, it is possible to obtain about 101 kg of fixed CO₂ and 2606 kg of sequestered CO₂.

Wood basic density expresses the amount of woody mass that constitutes a given volume and is, therefore, an important parameter in wood quality evaluation for several uses. In general, results in the present study are consistent with those in the literature, showing that 10-year-old trees, such as those in our study, have lower density than older trees, as expected. For example, in the studies of Santini Junior et al. (2010) with *A. sidifolia* (0.39 g.cm⁻³, adult trees in natural environment, age unknown); Andrade et al. (2009) in 25-year-old *G. integrifolia* (0.48 g.cm⁻³); Costa et al. (2014) in *G. ulmifolia* (0.55 g.cm⁻³, adult trees in natural environment, age unknown); Trautenmüller et al. (2016) in *I. marginata* (0.59 g.cm⁻³, adult trees in

natural environment, age unknown); and Coldebella et al. (2018) in *M. tinctoria* (0.54 g.cm⁻³, adult trees in natural environment, age unknown). Trees normally show a standard behavior from base-top direction of tree with higher densities at the base, reduced in DBH (diameter at breast height 1.30m), and increased or reduced until the canopy (Boschetti et al., 2020). In many studies to determine basic density, samples were taken at DBH level.

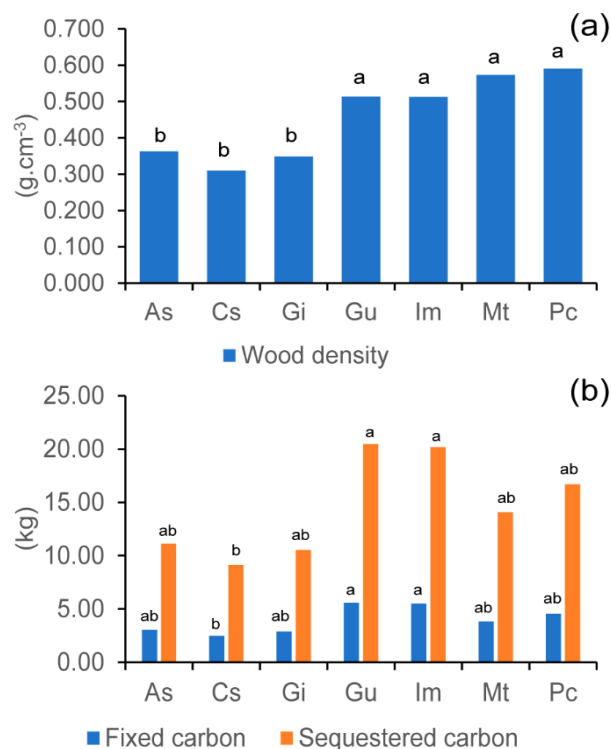


Figure 1. (a) Variation in wood density and (b) variation in fixed and sequestered carbon in seven 10-year-old species planted in the Commemorative Arboretum of 500 Years of Brazil. As = *Alchornea sidifolia*, Cs = *Ceiba speciosa*, Gi = *Galesia integrifolia*, Gu = *Guazuma ulmifolia*, Im = *Inga marginata*, Mt = *Maclura tinctoria*, and Pc = *Prunus cerasoides*. Different letters indicate statistical significance at $p < 0.05$ level (Tukey's test).

This type of sampling is normally undertaken by the ease and convenience; however, according to the literature, a decrease in DBH occurs for some species, and this can skew the results of the average value of this property for the entire tree (Boschetti et al., 2020). No consensus has been reached on the best sampling positions to estimate the average density of trees, using either destructive or non-destructive techniques (Couto et al., 2012). The trees that showed highest increment values in both height and diameter also showed lower densities, confirming the belief of many authors that the greater the growth in diameter, the lower the basic density. However, for *Eucalyptus* species, no direct relationship has been found between growth in diameter and basic density (Souza et al., 1986). Wood basic density can be altered according to species characteristics, as well as external influences, such as environmental variations and

silvicultural interventions. The causes of changes in wood density may also be indirect, as through the modification of other characteristics of wood, to the detriment of species characteristics, or the influence of the environment in which trees develop (Latorraca, 2000).

Table 2: Total CO₂ values per hectare (ha) of seven 10-year-old species planted in the Commemorative Arboretum of 500 Years of Brazil.

Species	Nº of trees	Total volume (m ³) one tree	Total volume (m ³) one tree x nº of trees	Fixed CO ₂ (kg)	Sequestered CO ₂ (kg)	Total fixed carbon (kg.ha ⁻¹)	Total carbon sequestered (kg.ha ⁻¹)
<i>Alchornea sidifolia</i>	25	0.01651	0.41282	2.99	10.96	74.63	273.91
<i>Ceiba speciosa</i>	25	0.01529	0.38215	2.49	9.12	62.14	228.06
<i>Gallesia integrifolia</i>	20	0.01713	0.34251	2.87	10.52	57.31	210.33
<i>Guazuma ulmifolia</i>	14	0.02172	0.30410	5.58	20.47	78.08	286.56
<i>Inga marginata</i>	27	0.02136	0.57680	5.50	20.19	148.52	545.07
<i>Maclura tinctoria</i>	15	0.01329	0.19940	3.83	14.06	57.45	210.86
<i>Prunus cerasoides</i>	51	0.01534	0.78213	4.55	16.68	231.83	850.83
Total	177						2606

For example, when comparing wood density of 10-year-old *G. integrifolia* in the present study with 25-year-old trees cited by Andrade et al. (2009), we found a slightly lower density in our investigation, confirming that basic density is influenced by planting age. Moreover, both fixed and sequestered CO₂ values were found to be highly dependent on wood basic density, i.e., the higher the density, the higher the fixed and sequestered CO₂ values will be. This is an indication that basic wood density must also be considered when selecting species for reforestation when the aim is fixing and sequestering carbon. Normally, only growth is taken into account in these types of studies.

Bellote et al. (2006) collaborated to evaluate the polynomial equations obtained for annual increase in carbon and mathematical models developed to estimate carbon accumulation as a function of DBH of *Pinus taeda* trees. They found and easily proved that the amount of carbon accumulated for trees with the same diameter is different when different locations are compared. Similarly, for average annual increase in tree height and diameter, it was observed that the trees of the same age, but in different sites, grow to a different diameter, resulting in greater increases in volume, biomass and, consequently, carbon accumulation.

When an area of one hectare is planted with trees of the same species, total carbon sequestered is estimated to be around 24 tons per hectare. Thus, 12-year-old *Hevea* sp. sequesters, on average, 62.10 tons of carbon per hectare, or 30%, in its living biomass (Fernandes et al., 2007).

The management of wooded areas in urban environments tends to decrease the levels of CO₂ in the atmosphere, helping to improve health and minimize global warming. However, few studies in the literature have reported on this topic in relation to urban green areas in Brazil (Rocha et al., 2017). Thus, although the data from our study is derived from trees in an arboretum, we have helped to fill this gap as Alberto Löffgren State Park is an urban

park, and our data summarize carbon sequestration in this urban environment.

In the present report, we look at the increase of CO₂ levels combined with the accumulation of carbon in the tissues of seven tree species growing in an urban setting. This is in line with an increased demand for studies reporting on the dynamics of natural forests that also aim to quantify the carbon stored during succession. Therefore, studies, such as ours, serve as a basis for the management and conservation of these native forest remnants. This goal is intensified by the need to assess the potential to sequester and accumulate carbon of each species individually in relation to the greenhouse effect (Figueiredo et al., 2015).

Torres et. al. (2017) report that native species that most contributed to carbon storage in forest fragments should be used in forest restoration programs that focus on mitigating climate change. Trees with DBH ranging between 5-25 cm already contribute to carbon storage, demonstrating their importance for forest fragments. Additionally, selection of native Brazilian species, to the detriment of exotic trees, is essential to avoid altering the environment for the other components of flora and fauna.

Conclusion

The species studied showed variation both within and between species. In some trees, the increment values in both height and diameter showed lower values of basic density. The fixed and sequestered CO₂ values are highly dependent on basic density. *Guazuma ulmifolia*, *Inga marginata*, *Maclura tinctoria*, and *Prunus cerasoides* had the best potential to sequester carbon. We confirmed reports in the literature that basic density is influenced by planting age. In this study, we also confirmed the value of understanding the potential of native species to sequester CO₂ as a key factor in urban afforestation plantations in cities.

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