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Biomass and carbon stock in progenies of cupuaçuzeiros according to age

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ABSTRACT

Cupuaçu (*Theobroma grandiflorum* Schum) is a small tree species that belongs to the family Malvaceae and is native to the Amazon. Forests capture and fix carbon in their components. Knowledge about carbon fixation in cupuaçu is incipient. The objective was to determine the biomass and the carbon stock in the components of two progenies of cupuaçu trees of different ages. The study was developed at the experimental station of Embrapa Amazônia Oriental, in Belém-Pará, Brazil. Seventy individuals were selected from the progenies PMI 186 and PMI 215, annually for seven years, to determine biomass and carbon stock in four plant components: stalk, leaves, primary branches and secondary branches. The mean biomass for stalk, leaves, primary branches and secondary branches were, respectively, 1352.5; 2412.0; 1748.5 and 2672.1 kg ha^{-1}. In the same order, the average carbon stock was 507.9; 892.3; 647.6 and 988.9 kg ha^{-1}. Cupuaçuzeiro presents low carbon stock in relation to other Amazonian species, but this plant can be adopted for cultivation because of the economic benefits that this activity generates.

Key words: fixation; dry mass; *Theobroma grandiflorum*

Biomassa e estoque de carbono em progênies de cupuaçuzeiros em função da idade

RESUMO

O cupuaçu (*Theobroma grandiflorum* Schum) é uma espécie arbórea de pequeno porte que pertence à família Malvaceae e é nativa da Amazônia. As florestas capturam e fixam carbono em seus componentes. É incipiente o conhecimento sobre fixação de carbono no cupuaçu. O objetivo foi determinar a biomassa e o estoque de carbono nos componentes de duas progênies de cupuaçuzeiro com idades distintas. O estudo foi desenvolvido na estação experimental da Embrapa Amazônia Oriental, em Belém-Pará. Foram selecionados 70 indivíduos das progênies PMI 186 e PMI 215, anualmente durante sete anos, para determinação de biomassa e estoque de carbono em quatro componentes da planta: caule, folhas, ramos primários e ramos secundários. As médias de biomassa para caule, folhas, ramos primários e ramos secundários foram, respectivamente, 1352,5; 2412,0; 1748,5 e 2672,1 kg ha^{-1}. Na mesma ordem, o estoque médio de carbono foi igual a 507,9; 892,3; 647,6 e 988,9 kg ha^{-1}. O cupuaçuzeiro demonstra baixo estoque de carbono em relação a outras espécies amazônicas, mas esta planta pode ser adotada para cultivo por conta dos benefícios econômicos que essa atividade gera.

Palavras-chave: fixação; massa seca; *Theobroma grandiflorum*

Introduction

The forests carry out the capture and fixation of carbon in the wood and other vegetal components, interesting to characterize the difference of fixation between the parts of the plant. The removal of carbon dioxide from the atmosphere occurs through photosynthesis and release through the transpiration process, where part of the carbon is stored in the various parts of plants (Watzlawick et al., 2003).

The forest is one of the main contributors to carbon sequestration on the planet, and it performs this process by capturing atmospheric gases that cause the greenhouse effect. As estimated by Cerri et al. (2006), the Amazon rainforest has the potential to sequester carbon of about 421 to 470 Tg $year^{-1}$, and approximately 30% of it is accumulated in the soil and the remaining 70% in aerial biomass (Carvalho et al., 2010).

It is valid to know the carbon concentration in the tree biomass since this knowledge helps with carbon stock estimates in the different ecosystems. In this context, the determination of carbon in different species is crucial to understanding the potential of forests (Martin & Thomas, 2011). It should be emphasized that the fixation process varies according to the environmental and morpho-physiological factors inherent to the plants (Watzlawick et al., 2014).

Cupuassu (*Theobroma grandiflorum Schum*) is a small tree species that belongs to the *Malvaceae* family, native to the Amazon region, considered one of the main plants of fruitful interest, much appreciated by the acidic pulp and intense aroma. In recent years, it has been gaining interest in countries of the European and Asian continents, notably England, Sweden, and Japan, as well as the United States and other countries of the American continent (Gonçalves et al., 2013).

The cupuassu tree went through a process of substitution of the extractivism to the domesticated form, all this considering the increase of the national and international demand, mainly for the pulp trade, that has been growing gradually in the last years. Interest in the cupuassu culture resulted in an increasing evolution of the planted area, mainly in the state of Pará.

Related to this increase in planted area, there is an increase in the chances of attacks by pathogens, such as the “witch´s broom”, a disease caused by the fungus *Crinipellis (Moniliophthora) perniciosa* (Stahel) Singer. Progenies of high resistance and productivity are developed to mitigate the losses caused by these agents. The progenies of cupuassu tree PMI 186 and PMI 215 are alternatives to cultivation that present good performance, besides good productivity. Alves & Cruz (2003) observed average fruit yield of 16.8 and 13.1 for progenies PMI 186 and PMI 215, respectively.

The culture of cupuassu stands out in the social and environmental contexts since it increases income generation and contributes directly to the net revenue of the state of Pará. Little is known about the carbon fixation in cupuassu plants, which makes valid the studies that determine the potential that this species present in this sense. Therefore, the objective was to evaluate dry mass production and carbon stock in two progenies of cupuassu trees as a function of age.

Materials and Methods

The experiment was conducted in field conditions, in an area of approximately 4,300 m^2, located at Embrapa Amazônia Oriental, Belém-Pará. The region has a monthly average temperature of 27.1 °C and relative humidity of 80%, situated under the geographic coordinates 01°24’59” and 01°27’40” of Latitude South, and 48°20'55'"and 48°26'59 " of West Greenwich Longitude (Figure 1).

The experimental design was completely randomized, in a factorial scheme 7 x 4 x 2, presenting five replications, totaling 280 experimental units. The treatments were seven ages (1-7 years), four plant parts (primary branches, secondary branches, stem, and leaves) and two progenies (PMI 215 and PMI 186).

The variables were measured annually during the seven years, and the progenies PMI 186 and PMI 215 were cultivated, distributed in 5 x 5 m spacing. Five plants of each progeny were selected for the quantification of the stem, leaves, primary branches (stem origin) and secondary branches (origin in the primary branches).

Each component of the cupuassu tree was collected and weighed to obtain fresh mass. Subsequently, samples of approximately 500 g of each collected material were packed in a paper bag and dried in a forced air ventilation oven at 70 ºC until constant weight was reached to determine the dry mass of the samples.

The dried material was ground in a Willey mill and after that, the carbon contents were determined. The biomass of the components in the tree was converted into C stock, multiplying the biomass by the average C content in each component of the total tree in the plants, using the Bezerra Neto & Barreto methodology (2004).

The analyzed variables were dry mass and accumulation of carbon in the aerial part. The results were submitted to analysis of variance and, when significant, means were compared by the Student-Newman-Keuls (SNK) test. The regression study was applied to evaluate the differences between the years. In the statistical analyses, the SISVAR computational software was used (Ferreira, 2011).

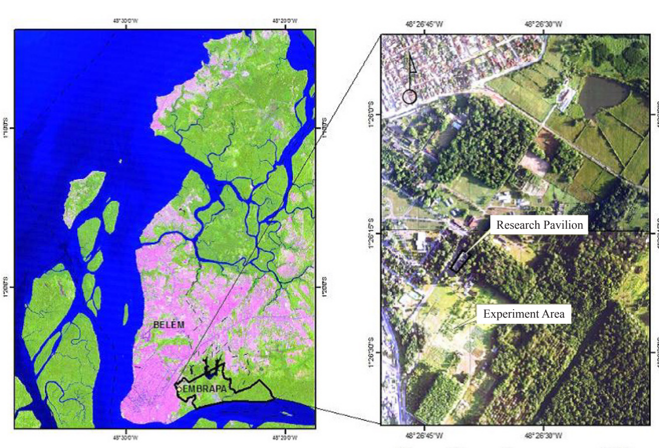

Figure 1. Geo-referenced map of the experimental conduction area, Belém - Pará, Brazil.

Results and Discussion

The dry mass production of the studied parts and the accumulation of carbon presented significant results for all treatments and their interactions. The carbon contents were not influenced by the treatments.

The dry mass production showed similar behavior for all parts of the plant, adjusting to the increasing linear regression model (Figure 2). The dry mass yields of the stem in the PMI 186 progeny during the evaluated years were equal to 44.6; 121.4; 389.6; 666.4; 977.3; 1240.5 and 1559.0 kg ha^{-1}. For the production of the PMI 215 progeny, the values corresponded to 69.2; 200.6; 345.8; 873.6; 905.8; 987.4 and 1086.6 kg ha^{-1} in the seven years evaluated (Figure 2A).

In the leaves, the dry mass production corresponded to 90.0; 158.4; 763.0; 1507.4; 1714.9; 2154.2 and 2541.8 kg ha-1 in the PMI 186 progeny in the characterized years. In the PMI 215 progeny, this yield was 97.0, 270.8, 675.4, 1458.4, 1493.8, 1851.4 and 2107.4 kg ha^{-1}, respectively, for the years studied (Figure 2B).

The dry mass production in the primary branches in the evaluated years was 42.4; 171.8; 539.8; 1206.8; 1243.5; 1553.4 and 1778.4 kg ha^{-1} for the PMI 186 progeny. In the PMI 215 progeny, they corresponded to 42.6; 184.2; 490.8; 1053.8; 1076.2; 1337.6 and 1518.4 kg ha^{-1} (Figure 2C).

As for the dry mass production in the secondary branches in the seven years of the survey, averages equal to 17.6 were observed; 34.0; 331.8; 1733.4; 2072.0 2681.9 and 3364.4 kg ha^{-1} for the PMI 186 progeny. In the same compartment, as a function of years, the PMI 215 produced a dry mass equal to 35.2; 83.0; 407.6; 1634.6; 1666.8; 2123.6 and 2518.8 kg ha^{-1} (Figure 2D).

According to Schumacher & Caldeira (2001), the biomass produced by plants tends to increase according to age. It should be noted that age and plant density is generally the aspects that most influence the distribution of biomass between the parts of plants. In a study by Caldeira et al. (2015) age and planting spacing were the factors that most affected the biomass distribution in *Araucaria angustifolia* (Bertol) Kuntze trees.

The highest leaf dry matter yield was obtained in progeny 186 with 2541.8 kg ha^{-1}. The largest increase was observed between the third and fourth year in progeny 215 (Figure 1B). In the last year characterized, greater biomass production was observed in the progenies, with better results for PMI 186 when compared to PMI 215.

The dry mass production of the primary branches in progeny 186 increased up to the seventh year with the highest production reaching 1,778.4 kg ha^{-1}, while the PMI 215 progeny produced 1,518.4 kg ha^{-1}. The largest increase occurred with the PMI 215 progeny, with a production of 722.4 kg ha^{-1} obtained in the fifth year (Figure 2C).

Dry mass production in the secondary branches of the PMI 186 and PMI 215 progenies increased by the age, with higher production in the PMI 186 progeny with 3,364.4 kg ha^{-1}. The largest increment was obtained in the PMI 186 progeny, with 1351.6 kg ha^{-1} representing a percentage of 41% in the fourth year (Figure 2D).

This trend in the distribution of biomass in forest species according to planting age was also verified by Ladeira et al. (2001) for different species of the *Eucalyptus* genus. In this study, the authors observed that at 15 months, the average proportion of canopy biomass was 40.4% and at 84 months, it was only 11.4%. In contrast, because it was considered a forest species, despite different families, cupuassu had great biomass growth of the canopy in the experiment.

In this sense, it is worth mentioning the statement by Otto (1994), who argues that during the initial phase of establishment of a forest, a large number of carbohydrates is directed to the production of biomass of the canopy. When analyzing the aerial biomass production in a coconut system, Silva et al. (2014) found that the Scion was the part of the plant with the highest biomass production.

The progenies of cupuassu tree showed linearly increasing behavior as a function of age in all parts of the plant, with higher stock in the PMI 186 progeny (Figure 3). The carbon stock presented by the PMI 186 progeny corresponded to 162.39 kg ha^{-1}, and for the PMI 215 progeny resulted in 141.28 kg ha^{-1}.

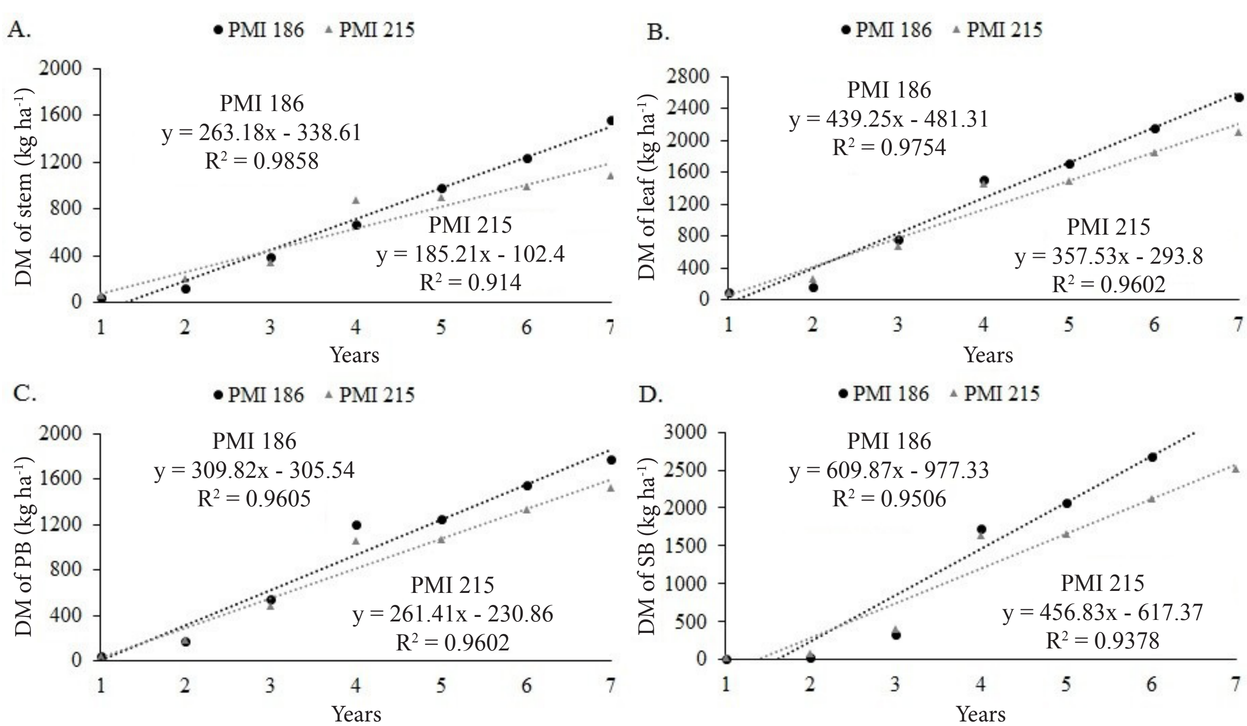

Figure 2. Dry mass production of the stem (A), leaf (B), primary branches (C) and secondary branches (D), in the progenies of PMI 186 and PMI 215 of different ages.

During the seven years studied, the stem showed carbon stocks equal to 16.5; 55.1; 144.3; 247.1; 361.3; 458.5 and 575.8 kg ha^{-1} for the PMI 186 progeny, while the PMI 215 progeny had 55.1; 74.3; 127.9; 323.7; 348.3; 365.6 and 402.2 kg ha^{-1} of carbon stored in the stem in the seven years evaluated (Figure 3A).

The carbon stock observed in the leaves for the PMI 186 progeny in response to the seven years was equal to 33.3; 58.6; 282.0; 558.7; 633.7; 795.9 and 938.3 kg ha^{-1}. For the PMI 215 progeny, in the seven years, means were found corresponding to 35.9; 100.5; 249.9; 539.1; 553.3; 685.8 and 781.2 kg ha^{-1} of fixed leaf carbon (Figure 3B).

As for the carbon stock found in the primary branches, mean values equal to 15.8; 63.6; 199.9; 447.1; 460.5; 575.2 and 658.5 kg ha^{-1} in response to the study years for the PMI 186 progeny. For the PMI 215 progeny, the carbon stocks were equal to 15.8; 68.3; 182.0; 390.0; 398.6; 495.4 and 562.4 kg ha^{-1} as a function of years (Figure 3C).

In the secondary branches, during the seven years, PMI 186 progeny was 6.5; 12.6; 122.8; 641.5; 766.9; 992.6 and 1245.2 kg ha^{-1} of carbon. In this same organ, averages equal to 13.0 were observed; 30.7; 150.7; 605.4; 616.9; 785.9 and 932.0 kg ha^{-1} of carbon fixed by the PMI 215 progeny in the seven years of study (Figure 3D).

The carbon stock obtained in the dry mass of the stem (Figure 3A) was higher in progeny 186 with 57.58 kg ha^{-1}. In the PMI 186 progeny, the highest increase was obtained in the seventh year, with 11.76 kg ha^{-1} corresponding to 21.0%. In the PMI 215 progeny, this highest increase was observed in the fourth year with 19.58 kg ha^{-1}, representing 49.3%.

In black acacia (*Acacia mearnsii De Wild*) at the age of four, Caldeira et al. (2003) obtained a percentage of carbon per hectare in the stem of 70% and 71% in the sixth year. When the results obtained in this research are related, it is verified that in the fourth year, this percentage was 17.77 and 16.71% in the sixth year. The reduction of the carbon content found in this work can be justified by the fact that the cupuassu tree invests more in the production of branches and leaves, and consequently more fruit production and fewer investments in the stem.

The highest carbon stock in leaf dry matter occurred in progeny 186 with 93.83 kg ha^{-1} (Figure 3B). The largest increase in carbon stock occurred in progeny 215 with 28.92 kg ha^{-1} between the fourth year and fifth year, representing 38.79%.

Schumacher & Caldeira (2001), evaluating six-year-old *A. mearnsii* found carbon stocks of 3.43 t ha^{-1} in leaves. Alves (2007), studying the quantification of the biomass production and the carbon content fixed by eucalyptus progenies at seven years, found for carbon stock leaves of 2.93 t ha^{-1}. Relating to the results obtained in this study, it is possible to observe that despite this difference in the carbon stock in the leaves, the lowest values for the carbon stock occurred in this part of the plant.Progeny 186 had the highest carbon stock in the primary branches (Figure 2C) with 65.85 kg ha^{-1}. The highest increase occurred in progeny 186 with 38.35 kg ha^{-1} with 49.2%, between the fourth and fifth year, and the progeny 215 in the same period 20.80 kg ha^{-1} representing 38.1%. The primary and secondary branches accounted for 54.09% of the percentage of the carbon stock verified in cupuassu tree plants. Studying the species *Avicennia schaueriana, Laguncularia racemosa* and Rhizophora *m*angle in the mangrove of the Sandi Site, Santos-SP, Sampaio et al. (2009) verified that the branches contributed with a higher percentage of carbon with 41.36%. Although they are species of different behaviors, it is inferred that the cupuasssu tree has potential as far as the carbon stock is concerned.

The carbon stock in secondary branches followed the same behavior of the other organs according to plant age (Figure 2D). Progeny 186 was accredited with a higher carbon stock, 124.52 kg ha^{-1} in the secondary branches, while at 215 with 93.20 kg ha^{-1}. The highest increase occurred in progeny 186 with 51.87 kg ha^{-1} between the fourth and fifth year with 41.8% and the progeny 215 in the same period had an increase of 45.47 kg

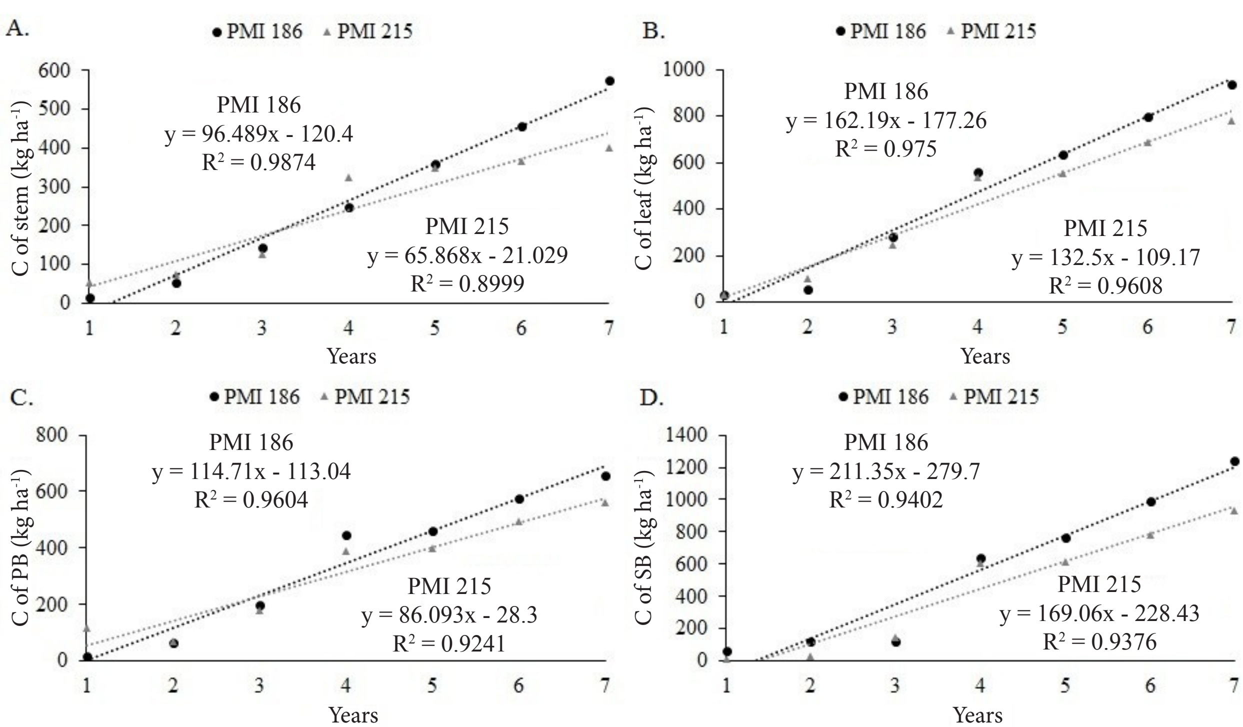

Figure 3. Carbon in the dry mass of the stem (A), leaf (B), primary branches (C) and secondary branches (D), in the progenies of PMI 186 and PMI 215 of different ages.

ha^{-1} representing a percentage of 59, 4%. From these results, it is deduced that, with a higher production of branches at the beginning of production, there will be a greater increase of biomass, a larger area capable of photosynthesis, a larger amount of carbon stock and consequently a higher production of fruits.

From the data obtained on the carbon stock present in the cupuassu tree, 83.58% were found in the crown (branches and leaves) and 16.42% in the stem. Teixeira et al. (1994) in a consortium with rubber tree x cocoa, 15 years old, obtained the estimated carbon stock in the crown (branches and leaves) of 66% in the cocoa crop. This difference can be justified due to factors such as age, the methodology used and density of individuals.

Caldeira et al. (2003) working with *A. mearnsii* on carbon production per hectare at four and six years old obtained 80 and 77% on live branches, respectively. These data can be related to this research that presented the percentage of 50.54% and 63.33% at the six years old in the respective parts of the plant. These differences can be justified by adverse factors such as spacing, plant architecture, and also by the fact that the cupuassu tree has been cultivated in a consortium, which demands competition for water, light, nutrients, and shade.

Conclusions

The dry mass production of the young shoots of cupuassu trees is increasing over the years, following the order secondary branches> leaves> primary branches> stem.

There is differentiation in the organs regarding the carbon stock, with the secondary branches being more expressive. Although the cupuassu tree presents low carbon stock when compared with other Amazon trees, the plant can be adopted because of the economic benefits presented by the crop.

The planting of cupuassu trees contributes to the recovery of CO_2 from the atmosphere and, consequently, reduces the environmental impacts caused by this gas.

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