CARBON STOCK AND REMOVAL OF CO_2 IN YOUNG STANDS OF FOREST RESTORATION IN RONDÔNIA

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Recebido para publicação: 13/07/2018 – Aceito para publicação: 21/01/2019

Resumo

Estoque de carbono e CO_2 removidos por plantios jovens de restauração em Rondônia. Este estudo visou quantificar o carbono estocado por povoamentos jovens, com espécies nativas, tendo como foco a restauração florestal, no norte do estado de Rondônia. Um inventário florestal foi realizado nos povoamentos com a instalação de 20 parcelas permanentes. Foram selecionadas 20 árvores de amostra localizadas perto de cada uma das parcelas, para a aplicação do método destrutivo. Análises laboratoriais do teor de carbono nos tecidos vegetais foram feitas nas amostras coletadas. A partição de biomassa por compartimentos foi avaliada e equações de regressão foram desenvolvidas para os dados dendrométricos coletados no inventário. A biomassa seca total foi distribuída da seguinte forma: 52% em fuste, 22% em galhos, 13% em folhas e 13% em raízes. O estoque de carbono médio calculado nos povoamentos foi de 15,7 $t.ha^{-1}$ aos 75 meses de idade, o que corresponde a uma fixação anual média de carbono de 2,5 $t.ha^{-1}.ano^{-1}$. Esses valores representam uma remoção de dióxido de carbono da atmosfera de 57,6 $tCO_2eq.ha^{-1}$ e 9,2 $tCO_2eq.ha^{-1}.ano^{-1}$. Concluiu-se que, apesar de serem jovens, os povoamentos possuem expressivo estoque de carbono, o que corresponde a cerca de 8,3% do que está armazenado na floresta nativa da Amazônia.
Palavras-chave: Amazônia, biomassa, espécies nativas, floresta, inventário.

Abstract

This study aims to quantify the carbon stock in young stands of forest restoration planted with native species on family farms in northern Rondônia State. A forest inventory of the stands was carried out in 20 permanent plots. Biomass of 20 sample trees located near each inventory plot was determined by the destructive method. Laboratory analyses of carbon content in plant tissues were made on samples brought from the field. Biomass partitioning by parts was evaluated and regression equations were applied from ordinary forest inventory data. The total dry biomass was distributed as follows: 52% in boles, 22% in branches, 13% in foliage and 13% in roots. The average carbon stock calculated for these stands was 15.7 $t.ha^{-1}$ at 75 months of age, which corresponds to an average annual carbon fixation of 2.5 $t.ha^{-1}.year^{-1}$. Such values represent a removal of carbon dioxide from the atmosphere of 57.6 $tCO_2eq.ha^{-1}$ and 9.2 $tCO_2eq.ha^{-1}.year^{-1}$. It was concluded that, in spite of being young, the stands have an expressive stock of carbon, which corresponds to about 8.3% of what is stored in the native Amazon rainforest.
Keywords: Amazon, biomass, native species, forest inventory.

INTRODUCTION

Since the beginning of the 1970s, high rates of deforestation have been observed in the Amazon (ARRAES *et al*. 2012) driven by the advancement of infrastructure, incentives for productive activities and stand growth in the region (PRATES; BACHA, 2011). The state of Rondônia has one of the highest rates of deforestation in the country, totaling 1,394 km^2 in 2016 (INPE, 2016), becoming a significant emitter of greenhouse gases (GHG) into the atmosphere and threatening the environmental services provided by the forest (BASTOS *et al*., 2015). The problem is augmented when one takes into account the low natural resilience of ecosystems, sometimes requiring human intervention to recover them.

Forest restoration in the Amazon means a concrete action to recover its biodiversity and ecological functions, and to mitigate GHG emissions (SILVA *et al*., 2015). There are currently several programs aiming at restoring degraded areas (ANDRADE *et al.*, 2014), but these actions can be more or less successful. Therefore, monitoring indicators must be used to understand the outcome of these restoration actions. The main indicators used in monitoring programs are assessments of soil cover, biomass, stratification, carbon sequestration rate, recruitment and mortality rates, and number and proportion among native plant species (UEHARA; GANDARA, 2011). The carbon stock in a forest area undergoing recovery may be an important indicator of the degree of success in restoration.

Biomass refers to the amount of plant material available in a given forest formation. Forest species have the ability to fix carbon for years or decades and store it in their structure (LITTON *et al*., 2007). Many biomass and carbon forest studies focus mainly on the quantification of nutrient cycling and quantification for energy, but others on the carbon sequestration potential of the restored forest areas.

However, to quantify carbon stocks in areas under restoration, it is indispensable to use methods that generate reliable estimates (ASHTON *et al*., 2012). It is important that indirect methods be calibrated with primary data collected from the field so that they reflect the local and regional reality of the structure of forests under restoration. Although labor-intensive, highly time-consuming, resource-demanding and environmentally sensitive, direct determinations are the basis for any modeling of biomass and carbon stocks in forests. Such determinations should be combined with forest inventory, respective laboratory analyses and modeling in order to generate reliable estimates of biomass and carbon.

Some key questions emerge when quantifying biomass and carbon in young forests. Most biomass and carbon equations published in the correlative literature were fitted to primary or mature forests with a distinct floristic composition, morphometry and wood density of tree species. Another relevant point is that estimates of biomass and carbon for tropical forests were generally derived from equations outside the usual biometric range in young stands of forest restoration. The use of an allometric equation outside of data limit fitted was can result in inaccuracy (MUGASHA *et al*., 2016; NAM *et al*., 2016) and gross errors, making it unusable.

There is a lack of knowledge about the biomass and carbon stocking process in forest restoration plantations, especially with consideration to their compartmentalization and modeling, thus leaving a gap in information regarding the potential of such forests as carbon sinks (MIRANDA *et al*., 2011). Therefore, the objective of this study is to quantify the carbon stocks in young forest restoration stands with native species in the Amazon region of Rondônia, to model it from tree measurement variables, and to evaluate the removal of dioxide carbon emissions from the atmosphere.

MATERIALS AND METHODS

The study was carried out in forest restoration stands planted between December 2010 and January 2011 in riparian forest allocated in agricultural and livestock farming, in the municipalities of Itapuã do Oeste and Cujubim, north of Rondônia. The climate of the region is tropical humidand the average annual temperature varys from 24°C to 26°C and rainfalls from 2,400 to 2,600 mm/year (GAMA, 2002).

Twenty permanent monitoring plots of forest restoration plantations, about 5.5 (75 months) years of age at the time of fieldwork, were randomly established in the stand. The sample units established have an area of 200 m^2 each, that is, ten meters wide and 20 m long. The selection was based on georeferenced maps of the region elaborated from recent satellite images intending to cover variations of site and plant characteristics, survival, uniformity, species composition and other attributes, as well as environmental zones.

All trees in the plots were identified, measured at *dbh* (diameter at breast height) with a pachymeter and a tape measure, and the *h* (total height) was measured with a telescopic ruler. Exsiccates were herborized and recorded in the Federal University of Rondônia, also with the support from the Museum Paraense Emilio Goeldi for botanical identifications.

Following the forest inventory, the most important species in phytosociology were listed to perform the determination of the biomass by the destructive method. Another criterion used was the diametric distribution for the selection of individuals to be cut and measured. The sampled individuals were: *Anacardium* sp., *Apuleia leiocarpa* (Vogel) J.F. Macbr., *Cassia grandis* L. f., *Cecropia* sp., *Cedrela odorata* L., *Ceiba pentandra* (L.) Gaertn., *Cordia alliodora (*Ruiz & Pav.) Cham., *Dipteryx odorata* (Aubl.) Willd., *Enterolobium schomburgkii* (Benth.), *Enterolobium* sp., *Handroanthus* sp., *Hevea brasiliensis* (Kunth) Müll. Arg., *Hymenaea courbaril* L., *Inga cylindrica* (Vell.) Mart., *Parkia multijuga Benth., Schizolobium amazonicum* (Huber ex Ducke) Barneby and *Stryphnodendron* sp. The diameter amplitude ranged from 5.44 to 13.05 cm and the height ranged from 5.23 to 10.97 m (SANQUETTA *et al*., 2017).

To determine the biomass, 20 trees were sampled and cut dawn, based on the availability of financial resources and manpower for the field activities. After that, they were separated into bole/trunk, branches, foliage and

Electronic ISSN 1982-4688
DOI: 10.5380/rf.v50 i1. 60494

miscellaneous (fruits, flowers, shoots, among others). The root system was excavated to a depth of 50 cm and all visible and distinguishable roots were collected and cleaned. The parts of the trees were weighed separately using a digital scale with a precision of 100 g, obtaining the fresh weight of each one. Fresh samples of about 500 g of all biomass parts were taken from the field and packed in a single packaging each to be taken to the laboratory. These samples were oven-dried by air at 65ºC until constant weight. Then, the conversion into dry biomass of each compartment was carried out, according to equation 1:

$$db_{ij}=fb_j\frac{(100-mc_{ij})}{100} \qquad \text{(Equation 1)}$$

Where:
db_j = dry biomass of the compartment j of the tree i (kg);
fb_j = fresh biomass of the compartment j of the tree i (kg);
mc_{ij} = moisture content of samples from the compartment j of the tree i (%).

To obtain the total dry biomass of each tree, we used equation 2:

$$db_i=\sum_{j=1}^{n} b_{ij} \qquad \text{(Equation 2)}$$

where:
db_j = total dry biomass below and above the soil of the tree i (kg);
b_{jj} = dry biomass of the compartment j (kg) of the tree i.

The basic specific masses of wood samples (ρ_i) were determined by the relation between the dry matter of the bole of each tree and its volume. The bole volume was determined by the method of Hohenadl, with relative sections of 10% of the bole defined from the base to the main branch or morphological inversion point.

Biomass Expansion Factor and Root-to-Shoot Ratio were calculated as follows:

$$BEF_i= ba_i/bb_i \qquad \text{(Equation 3)}$$

$$R_i= br_i/ba_i \qquad \text{(Equation 4)}$$

Where:
ba_j = dry aboveground biomass of the tree i (kg);
bb_j = dry biomass of the bole of the tree i (kg);
br_j = dry biomass of roots of the tree i (kg);

Then, the dry biomass samples were fractionated and milled with a mesh size 50, corresponding to a 0.979 mm sieve aperture, in a Tecnal Wiley mill, model TE-648. The analysis of carbon contents of each tree per part was carried out on the LECO analyzer, model C-144, which uses the dry combustion method.

The carbon contents were multiplied by the respective biomass of each tree part, generating the respective carbon stocks. By summing the carbon stocks in each tree, the individual carbon stock was obtained:

$$c_{ij}=bs_{ij}*tc_{ij} \qquad \text{(Equation 5)}$$

$$c_i=\sum_{j=1}^{n} c_{ij} \qquad \text{(Equation 6)}$$

where:
c_{ij} = carbon stock in the compartment j of tree i (kg);
cc_{ij} = carbon content of the samples collected in the field for the compartment j and the tree i ($gc.gb^{-1}$);
c_i = total dry biomass - shoot and root of the tree i (kg).

Five regression models were used to estimate the biomass from the data of *dbh* and *th* from inventoried trees, two were single entry (only with *dbh* as an independent variable) and three double entry (both independent variables). A model was added in the tests incorporating the variable basic specific mass of wood (Table 1).

The assessment of the adjustment quality of the resulting equations was done on the basis of the following criteria: adjusted coefficient of determination ($R^2_{aj.}$), standard error of estimate in percentage ($S_{yx}\%$) and graphical analysis of residuals.

The best performance equation was applied to the inventoried data (dbh and th) to estimate the biomass. This value was multiplied by the biomass-weighted carbon contents of each part of the tree (bole, branches, foliage and roots) to obtain the carbon stocks for each individual inventoried. Then, the individual carbon stocks were summed in each plot and converted into hectares taking into account a proportionality factor 50, which represents the area ratio of 1 hectare (10,000 m^2) per area of each plot. The results were then analyzed statistically by the Simple Random Sampling Process.

Table 1. Biomass regression models tested for 20 trees measured in young stands of forest restoration in the north of Rondônia.

Tabela1. Modelos de regressão de biomassa testados para 20 árvores medidas em povoamentos jovens de restauração florestal no norte de Rondônia.

Author	**Model**	**Eq.**
Kopezky-Gehrhardt	$\hat{b}_{si} = b_0 + b_1\, dbh^2_i$	7
Husch	$\log \hat{b}_{si} = b_0 + b_1 \log(dbh_i)$	8
Spurr	$\hat{b}_{si} = b_0 + b_1 (dbh_i^2 h_i)$	9
Spurr logarítmico	$\log(\hat{b}_{si}) = b_0 + b_1 \log(dbh^2_i h_i)$	10
Schumacher-Hall	$\log(\hat{b}_{si}) = b_0 + b_1 \log(dbh) + b_2 \log(h_i)$	11
Chave	$\log(\hat{b}_{si}) = b_0 + b_1 \log(dbh_i) + b_2 \log(h_i) + b_3 \log(\rho_i)$	12

log = logarithm in base 10; = $\hat{b}_i$ = estimated total dry biomass (kg); b_0, b_1 and b_2 = regression coefficients; dbh_i =Diameter at breast height ; h_i = height (m) of the tree *i*; ρ_i = basic specific mass of wood of the bole (gcm^{-3}).

In order to estimate the removal in equivalent carbon dioxide (CO_{2eq}), stoichiometry was used considering the mass of the carbon dioxide molecule (44) converted from the atomic mass of the carbon element (12) according to equation 13:

$$CO_{2eq.} = C * 44/12 \qquad \text{(Equation 13)}$$

where:
CO_{2eq}. = removed carbon dioxide ($t.ha^{-1}$);
C = carbon stock in the stand ($t.ha^{-1}$).

RESULTS

All twenty individuals sampled for biomass and carbon had individual total dry biomasses ranging from 8.91 to 106.32 kg, with a mean of 32.33 kg. The individual carbon stocks ranged from 3.98 to 47.39 kg, with a mean of 14.56 $kg.plant^{-1}$ (Table 2).

The biomass of these twenty selected trees had the following distribution in parts (pools): 52% in boles, 22% in branches, 13% in foliage and 13% in roots, which denotes an average biomass expansion factor (*BEF*) of 1.67 and a root ratio (*R*: *root-to-shoot ratio*) of 0.15.

The analyzed equations presented a low degree of adjustment for both single entry and double entry models. However, the incorporation of the variable basic specific mass of wood improved fit indicators (Table 3, Figure 1). In spite of the improvement of the fit, this model has a more limited application than the others because of the difficulty of using the independent variable ρ, since the stand is composed of many species with different characteristics with

FLORESTA, Curitiba, PR, v. 50, n. 1, p. 991 - 1000, jan/mar 2020
Sanquetta, R. *et.al*
Electronic ISSN 1982-4688
DOI: 10.5380/rf.v50 i1. 60494

respect to this variable, and data of forest inventory generally do not contemplate the individual collection of basic specific mass of wood. An alternative would be the use of an average value per species, but this measure could worsen estimates. Therefore, it was preferred to use the Schumacher-Hall equation for inventory data because the difference of the total biomass estimated for the 20 trees measured using the two models was less than 1%.

Table 2. Description of 20 trees measured for biomass and carbon quantification in young stands of forest restoration in the north of Rondônia.
Tabela 2. Descrição de 20 árvores medidas para quantificação de biomassa e carbono em povoamentos jovens de restauração florestal no norte de Rondônia.

Tree (*i*)	**Species**	dbh_i **(cm)**	h_i **(m)**	db_i **(kg)**	c_i **(kg)**
1	*Stryphnodendron* sp.	10.5	8.8	57.73	25.60
2	*H. pulcherrimum*	6.05	6.15	11.05	4.92
3	*I. cylindrica*	10.98	8.6	79.01	35.30
4	*Enterolobium* sp.	5.89	5.8	11.81	5.22
5	*Handroanthus* sp.	12.1	8	36.83	16.36
6	*S. amazonicum*	12.73	10.8	53.1	23.82
7	*P. multijuga*	11.94	7.7	16.05	7.16
8	*H. courbaril*	13.05	9.8	106.32	47.39
9	*Anarcadium* sp.	9.87	8.9	29.09	12.93
10	*E. schomburgkii*	5.73	6.3	8.91	3.98
11	*H. brasiliensis*	8.12	9.35	20.06	9.04
12	*S. amazonicum*	7.42	7.35	14.88	6.86
13	*C. odorata*	7.51	6.65	15.79	7.03
14	*H. courbaril*	5.44	5.23	10.71	4.90
15	*A. leiocarpa*	9.9	9.5	48.36	22.28
16	*Handroanthus* sp.	12.29	8.46	23.48	10.79
17	*C. alliodora*	12.19	10.97	31.55	14.44
18	*D. odorata*	7.48	6.55	22.58	10.43
19	*C. pentandra*	10.66	6.25	13.74	6.15
20	*Cecropia* sp.	12.41	11.8	35.64	16.51

dbh = diameter at breast height (cm); *th* = total height (m); *b* = total individual dry biomass (kg); *c* = total individual carbon stock (kg).

Table 3. Fit statistics and coefficients of biomass regression models tested for 20 trees measured in young stands of forest restoration in the north of Rondônia.
Tabela 3. Estatísticas de ajuste e coeficientes de modelos de regressão de biomassa testados para 20 árvores medidas em povoamentos jovens de restauração florestal no norte de Rondônia.

Eq.	b_0	b_1	b_2	b_3	***MCF***	R^2 ***aj.***	***Syx%***
5	0.5807	0.3204	-	-	-	0.3810	63.95
6	-0.30283	1.7648	-	-	1.12	0.3772	64.14
7	6.8195	0.0292	-	-	-	0.4018	62.86
8	-0.5689	0.6958	-	-	1.11	0.4064	62.62
9	-0.7179	0.9402	1.3454	-	1.11	0.3834	65.67
10	0.4054	0.9546	0.2955	0.899961	1.06	0.8041	38.15

MCF = Meyer correction factor; $R^2aj.$= adjusted coefficient of determination; *Syx%*: standard error of estimate in percentage; b_0, b_1, b_2 and b_3 = regression coefficients.

The forest/floristic inventory revealed the occurrence of 85 tree species, average density of 1,193 boles.ha^{-1} and basal area of 12.1 m^2.ha^{-1}. The average biomass stock was 34.9 t.ha^{-1} and the carbon stock was 15.7 t.ha^{-1}. Considering the age of the stand (75 months), these values correspond to an increase of 5.6 t.ha^{-1}.year^{-1} in terms of biomass and a carbon sequestration of 2.5 t.ha^{-1}.year^{-1} (Table 4).

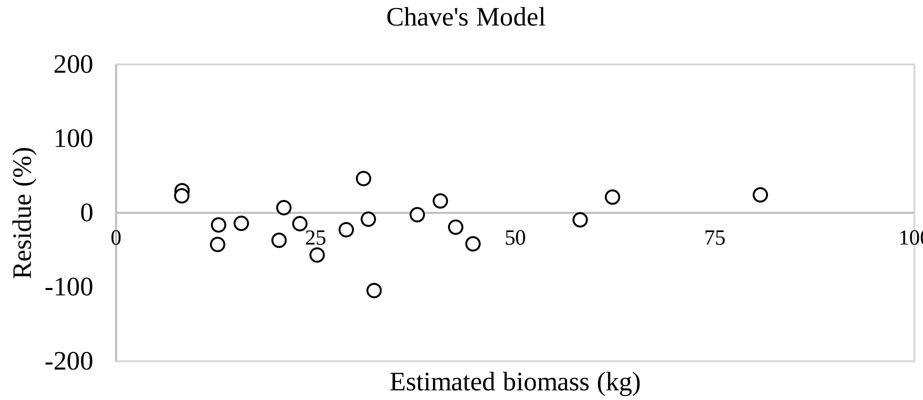

Figure 1: Residual distribution in % for the Chave's model tested for biomass data adjustment of 20 trees in the north of the state of Rondônia.

Figura 1: Distribuição residual em% para o modelo de Chave testada para ajuste de dados de biomassa de 20 árvores no norte de Rondônia.

Table 4. Estimates of density, basal area and biomass and carbon stocks in 20 forest inventory plots in young stands of forest restoration in the north of Rondônia.

Tabela 4. Estimativas de densidade, área basal e estoques de biomassa e carbono em 20 parcelas de inventário florestal em povoamentos jovens de restauração florestal no norte de Rondônia.

Plot	***N*** **ind.ha^{-1}**	***G*** **(m^2.ha^{-1})**	***B*** **(t ha^{-1})**	***C*** **(t ha^{-1})**
1	1,400	13.38	26.42	11.89
2	2,500	17.61	59.08	26.59
3	1,100	13.23	49.82	22.42
4	1,200	10.72	38.18	17.18
5	1,000	11.67	30.30	13.63
6	1,550	12.43	41.80	18.81
7	1,450	9.87	29.08	13.09
8	2,150	13.15	42.99	19.35
9	1,900	15.16	42.76	19.24
10	1,100	6.30	18.08	8.13
11	1,100	14.73	37.26	16.77
12	1,000	8.26	21.89	9.85
13	650	6.44	17.92	8.06
14	550	3.68	13.84	6.23
15	650	8.54	27.76	12.49
16	450	11.97	28.78	12.95
17	1,100	23.52	68.94	31.02
18	1,100	18.78	42.16	18.97
19	1,100	10.37	29.94	13.47
20	800	13.05	31.06	13.98

N: number of individuals; *G*: basal area per unit area; *B* = total dry biomass per unit area; *C*: total carbon stock per unit area.

FLORESTA, Curitiba, PR, v. 50, n. 1, p. 991 - 1000, jan/mar 2020
Sanquetta, R. *et.al*
Electronic ISSN 1982-4688
DOI: 10.5380/rf.v50 i1. 60494

In this study, a direct and linear relation between the basal area of the inventory plots and the carbon stored in them (Figure 2) was evidenced. The basal area is a readily available variable in forest inventories, and this relation can greatly speed up estimates of biomass and carbon in forests.

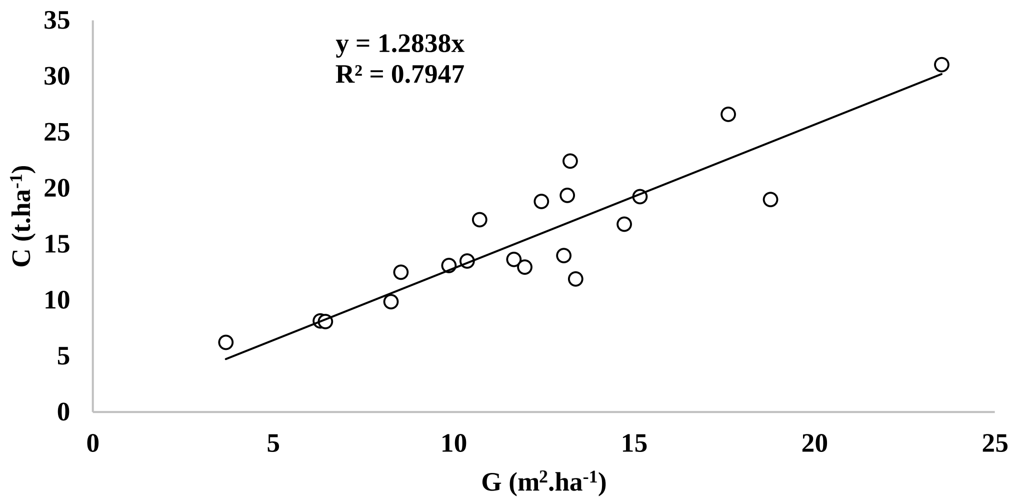

Figura 2: Relação entre área basal e estoque de carbono em povoamentos jovens de restauração florestal no norte de Rondônia.
Figure 2: Relation between basal area and carbon stock in young stands of forest restoration in the north of Rondônia.

The removal of carbon dioxide from the atmosphere by stands, calculated from carbon stocks and stoichiometry, was 57.6 $tCO_{2eq}.ha^{-1}$, corresponding to 9.2 t $CO_{2eq}.ha^{-1}.year^{-1}$.

DISCUSSION

There are almost no publications on values of *BEF* and *R* in the literature addressing biomass and carbon storage in forest restoration. Not even the IPCC has default values for these quantities. The default R value of the IPCC for tropical forests is 0.37, with a variation of 0.20 to 0.56 depending on the ecological zone.

By deducting *BEF* and *R* for forest restoration projects in Brazil from works on the Atlantic Forest (NOGUEIRA Jr *et al*., 2014), a much higher value is reached for both: 2.40 and 1.92 for *BEF*, respectively, and 0.25 and 0.41 for *R*, respectively. Characteristics of the site and the morphometry of the species may be reasons explaining such differences.

The values found in this study for *BEF* and *R*, on the other hand, are comparable to those found in pure commercial stands of *Pinus* spp. (SANQUETTA *et al*., 2011) and *Populus* sp. (SCHIKOWSKI *et al*., 2015).

The equations of biomass analyzed in this study presented a medium degree of adjustment for both the single input and the dual input models. However, the incorporation of the variable basic specific mass of wood improved greatly adjustment indicators (Table 3, Figure 1).

If the average carbon estimated increase in this study was constant over time, it would take about 75 years for the C stock of the native forest to be reached. However, other authors found biomass values in the northern region of Rondônia between 288 and 534 $t.ha^{-1}$, which would be equivalent to 130 to 240 t of carbon per hectare (KAUFFMANN *et al*., 2009). Therefore, the theoretical calculation of the recovery of the carbon stock by the stands of forest restoration under consideration would be between 52 and 96 years. However, it should be noted that growth in young plantations is faster at the beginning and decreases as life space occupancy and competition increase. Site-related factors, forestry activities and exogenous events may also influence the carbon sequestration process of restoration stands, making this calculation relatively more complex than it appears to be.

There is little information on the potential of forest restoration plantations to store carbon in the Amazon Rainforest. In other biomes, there are more studies (e.g., NOGUEIRA JR *et al*., 2014), mainly in the Atlantic Forest. Great differences in rates of biomass increase in forest restoration stands have been observed for both Cerrado and Atlantic Rainforest. The literature shows carbon stock values at ages close to that of this study, ranging from 7 to 32 $t.ha^{-1}$, which means that the stands in our study are in a medium condition in terms of productivity.

We can also make a parallel between the carbon stocks in the stands of this study with young forests under natural regeneration. Studies of biomass and carbon stocks in the Amazon forest found variations between 30-40 $t.ha^{-1}$ which could reach up to 50 $t.ha^{-1}$ in low plateau forests, and ecological tension with approximately 14 years of regeneration and units with only 19 $t.ha^{-1}$ in areas of minor secondary vegetation. Carbon stocks evaluation of forest fragments vegetation in tropical landscapes changed by anthropic activities and values range from 5.24 to 25.93 $t\ C.ha^{-1}$. Some authors state that a secondary forest with 10 years of age can assimilate about 6 to 10 $t\ C.ha^{-1}\ year^{-1}$, reducing to approximately 4.0 to 7.0 $t\ C.ha^{-1}\ year^{-1}$ at 20 years; at 80 years, this value falls to 2.0 $t\ C\ ha^{-1}year^{-1}$, reaching its equilibrium in 100 years, with an assimilation rate of 0.97 $t\ C.ha^{-1}.year^{-1}$ (FEARNSIDE; GUIMARÃES, 1996). Considering an average stock of 188 t of carbon per hectare in primary native forest (RODRIGUES et al., 1999), it can be said that the carbon accumulated by these young stands of restoration corresponds to about 8.3% of the reference value in the predominant ecosystem of the region, which mainly comprises the Open Ombrophylous Forest (Open Rain Forest).

Torres and Lovett (2012) considered that the use of equations at a settlement level is very promising, since the basal area, among other predictive biomass and carbon variables that can be quickly measured in the field, may facilitate their application based on data collected in conventional forest inventories. By using the equation of Figure 2, it is possible to estimate the carbon stock (and biomass) from the basal area, applying it to stands with similar characteristics.

The expansion of researches like this one, on family farming properties, may guide payment for environmental services policies. These policies can generate alternative income for thousands of families in the near future, allowing the maintenance of ecosystem services and, consequently, improvements in conservation activities in Amazon Rainforest.

These young restoration stands grow faster than the mature forest and then have a great capability to store carbon in their biomass. Therefore, they are important allies to the mitigation of GHG emission. Considering that a flex-fuel vehicle, which uses gasoline as the main fuel, emits 2.21 kg $CO_{2}.l^{-1}$ of petrol and 1.53 $CO_{2}.l^{-1}$ of hydrated ethanol (GHG PROTOCOL, 2018), the annual rate of fixation/sequestration per hectare of the stands would correspond to the consumption of 5,300 l of fuel.

CONCLUSIONS

- There is a great allocation of biomass and carbon in the woody part of the trees, particularly in boles, followed by branches, foliage and, finally, roots.
- Single and double regression equations tested for biomass present a medium performance in terms of fit quality and the addition of the variable basic specific mass of wood improves their performance.
- The relation between basal area and carbon stock per unit of area allows to obtain estimates only with classical forest inventory variables, without requiring individual estimates, facilitating their practical application.
- Theoretical estimation of the time of re-composition of the carbon stock to reach the level of the primary forest is 52 to 96 years.
- The removal of carbon dioxide from the atmosphere by the stands is 57.6 $tCO_{2eq}.ha^{-1}$ or 9.2 $tCO_{2eq}.ha^{-1}.year^{-1}$. Therefore, the potential of forest restoration plantations for the mitigation of greenhouse gases is evident.

ACKNOWLEDGMENTS

Thanks to Petrobras for the support through the Socio Environmental Program.

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