Nativa, Sinop, v.4, n.4, p.199-205, jul./ago. 2016.
Pesquisas Agrárias e Ambientais
DOI: 10.14583/2318-7670.v04n04a03
http://www.ufmt.br/nativa

ISSN: 2318-7670

Growth and production of paricá wood in two plantations in the north of Mato Grosso, Brazil

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Recebido em janeiro/2016; Aceito em maio/2016.

ABSTRACT: The objective of the present study was to describe the increase in diameter, height and volume of trees of *Schizolobium amazonicum* Huber ex Ducke and adjust a mathematical model to describe growth in terms of total volume in two plantations in the north of Mato Grosso, Brazil. Data were obtained through full analysis of the stem of 12 trees collected in two plantations. Four functions of volume growth according to age were tested. Growth in diameter, height and volume were compared through analysis of variance and Tukey test. The average growth for the two plantations, which had 16 years of age, in terms of DBH and total height were 30.1 and 32.2 cm; 29.2 and 23.9 m and volumetric production was 1.04 and 0.96 m^3, respectively, for the plantations one (1) and two (2). There was a statistical difference ($p < 0.001$) between the plantations only for the variable total height from the eighth year. The Richard's (R^2aj 0.82) and Logistic (R^2aj 0.65) models had the best fit for the plantations one and two, respectively. Results pointed to the conclusion that S. amazonicum has rapid growth in the study area but this is still lower than the growth of the species in other Amazon states such as Pará, Acre and Rondônia.

Keywords: reforestation, stem analysis, modeling, Amazon.

Crescimento e produção de madeira de paricá em dois plantios no norte de Mato Grosso

RESUMO: Objetivou-se com o presente estudo, descrever o crescimento das variáveis: diâmetro, altura e volume e ajustar um modelo matemático para descrever o crescimento em volume total de árvores de *Schizolobium amazonicum* Huber ex Ducke, em dois plantios no Norte do estado de Mato Grosso. Os dados foram obtidos mediante análise de tronco completa de 12 árvores coletadas em dois plantios. Foram testados quatro funções de crescimento volumétrico em função da idade. Os dados de crescimento em diâmetro, altura e volume foram comparados pela análise de variância e teste de Tukey. As médias do crescimento para os dois plantios, aos 16 anos para o dap e altura total foram de 30,1 cm e 32,2 cm; 29,2 m e 23,9 m, e a produção volumétrica foi de 1,04 e 0,96 m^3, respectivamente para os plantios um (1) e dois (2). Houve diferença estatística ($p < 0,001$) entre os plantios apenas para a variável altura total a partir do oitavo ano. Os melhores modelos de crescimento volumétrico foram o de Richard (R^2aj 0,82) e Logistic (R^2aj 0,65) para o plantio um e dois, respectivamente. Conclui-se que S. amazonicum possui rápido crescimento na região de estudo, no entanto, é inferior ao crescimento em outros estados da Amazônia como Pará, Acre e Rondônia.

Palavras-chave: reflorestamento, análise de tronco, modelagem, Amazônia.

1. INTRODUCTION

The forthright decay of timber industry in the Amazon region stems from an intensive and selective exploratory process (ASNER et al., 2005) based on the preferential comercial use of better quality arboreal individuals, leading to depletion of forests (MODES et al., 2014). According to De Graaf et al. (1999), exploitation of tropical forests is based on the selective extraction of a few commercial species, causing great pressure on the remaining populations. As a result, forest plantations have gained increasing importance in the Amazon because of the need to reforest degraded areas and to meet the growing scarcity of raw materials (MODES et al., 2014). In 2014, the area occupied by forest plantations in Brazil totaled 7.74 million hectares, of which 89 081 ha (1.15%) is represented by the species *Schizolobium amazonicum*, commonly known in the Brazilian Amazon as paricá, and concentrated mainly in the states of Pará and Maranhão (SFB, 2013; IBÁ, 2015).

Paricá occurs naturally in upland areas and high floodplains, in high and low fertility soils, concentrated in the Brazilian

Amazon, with small occurrence in Peru, Colombia, Venezuela and Bolivia (GAZIEL FILHO et al., 2007). In native forests, paricá may reach 20 to 30 m tall and 60-80 cm in diameter at 1.30m (DBH). The heartwood and sapwood are not differentiated from white-straw color with yellow and pink patches (FERREIRA; MELO, 2006). The *S. amazonicum* wood is mainly used for production of veneer and plywood, but it can also be used for liners, toothpicks, paper, furniture, finishes and frames (ABRAF, 2013). Even without the adoption of breeding programs, paricá has average annual productivity of 20 to 30 m^3 ha^{-1} $year^{-1}$, similar to the growth range of *Pinus spp.*, which is 25 to 30 m^3 ha^{-1} $year^{-1}$and superior to teak's productivity, which is 15 to 20 m^3 ha^{-1} $year^{-1}$ (IWAKIRI et al., 2010).

The silvicultural and technological potential of *S. amazonicum* has demonstrated its technical and economic feasibility for reforestation in the North and Northeast of the country (VIDAURRE et al., 2012). The increasing demand for wood to meet the need of raw materials market calls for the need to carry out detailed studies to predict the growth of forest species such as *S. amazonicum*. Knowledge on the main dendrometric variables and silvicultural performance of this species in the state of Mato Grosso is incipient. The literature on this topic report the results obtained especially with this species in plantations of Pará State, such as the works of Ribeiro et al. (2004), Viégas et al. (2007), Colli et al. (2010), Hoffman et al. (2011), Vidaurre et al. (2012), Santos (2012) and Melo et al. (2014).

The estimated productivity of a population or a species can be assessed by means of stem analysis inside permanent and/or temporary plots. This is a technique for retrospective measurement of the growth of individual trees (SILVA; PAULA NETO, 1979). In forestry companies, stem analysis coupled with the continuous inventory has allowed the development of allometric equations, recovery of growth rates and analysis of the effect of silvicultural treatments and management practices on the growth of forest species (MIRANDA et al., 2014).

Therefore, it is crucial to know the characteristics of silvicultural species in order to aid the decision making process of forest producers, in their administration of commercial plantations in the state of Mato Grosso. The present study aimed to describe the growth of the variables diameter, height and volume and adjust a mathematical model to describe the growth in terms of total volume of individuals of *Schizolobium amazonicum* Huber ex Ducke in plantations in the north of Mato Grosso.

2. MATERIAL AND METHODS

2.1. Location and characterization of the study area

The study area is located in the municipality of Sinop, North of Mato Grosso, about 500 km from the capital of the state, Cuiabá. Its average altitude above sea level is 384 m, with average maximum and minimum monthly temperature of 34°C and 24°C, respectively, and the average annual rainfall of 2,090 mm. This region is characterized as a zone of edaphic and climatic transition between Brazilian cerrado and Amazonia rain forest. Its vegetation is classified as semi-deciduous submontane forest with emerging canopy and its climate, according to Köppen, is Aw (BRASIL, 1980).

The area has low fertility soil classified as Red-Yellow Dystrophic Latosol. The texture is sandy with clay, with water pH of 4.5, low levels of potassium and phosphorus, and 2.4% of organic matter. Its particle size composition is 54% of sand, 6% of silt and 40% of clay (BRASIL, 1980).

Data collection was performed in two homogeneous and 50 km equidistant plantations of paricá. The plantation one (1) is owned by the Research, Assistance and Rural Extension Company SA of Mato Grosso- EMPAER-MT, located in the coordinates 11°58'52" S and 55°33'43" W. The spacing in this plantation is 12 m^2 (4 x 3 m). The plantation two (2) belongs to the Madenorte Agroindustrial Company S/A locatated in the coordinates 11°39'38" S and 55°26'22" W. The spacing is 6 m^2 (3 x 2 m). In plantation one (1), plants received topdressing in the pit with 100 g of lime and 200 g of NPK formulation (10-10-16) until the third year of age. The same fertilization was applied to plantation two (2), but only in the first year.

2.2. Data collection and stem analysis

Six (6) paricá trees were selected and uprooted in each forest plantation, those trees that were close to the quadratic mean diameter (dg). According to Machado and Figueiredo Filho (2006), this diameter describes the tree that is closest to the average volume of the population and is obtained by the Eq. 1:

$$dg = \sqrt{\frac{40000 \cdot \overline{g}}{\pi}} \quad \text{where:} \quad \overline{g} = \frac{\sum_{i=1}^{n} g_i}{n} \qquad (1)$$

where:

dg - root mean square diameter, cm;
$\overline{g}$ - average of cross-sectional areas, m^2;
gi - cross-sectional area of class i, m^2;
n - number of trees.

The variables obtained with the uprooted trees were: diameter at breast height (cm) and total height (m) of each sample-tree. In order to carry out the full stem analysis (ANATRO), timber discs at 0.1; 0.7; 1.3 m height and, from that point onwards, at every meter up to the total height, were taken from each sample-tree, as suggested by Finger (2006). Disks were pre-identified and oven dried at 40°C.

Sampled cross-sections were polished in different thicknesses (60 to 600 mm $grains^{-2}$), resulting in better contrast of growth rings. These samples were scanned along with a scale for calibration with Epson Perfection V750 Pro scanner with a resolution of 1200 dpi (dots per inch). The distance between growth rings was determined using the software Image Pro Plus® with accuracy of 0.01 units of measurement. Results were exported to Microsoft Excel for analysis of the average annual and current diameter increment. Because age of the samples was known and there was no doubt about false rings, cross-dating was not made.

The variable height was obtained following the method proposed by Carmean (1972) whose basic principles are that the annual height growth is constant for any year, regardless if it is fully or partially contained within the same section, and that the disc is taken, on average, in the half of the annual height growth. Mathematically, these two principles are described in the Eq. 2. The Smalian method was used to obtain the volume at various ages. The volume of each section is calculated considering a cylinder where the area is the product of the average cross-sectional areas of the bottom and top sections and the length of the section, considering the last section of the geometry of a cone (FINGER, 2006). This calculation was performed from Eq. 3.

$$H_{ij} = h_i + \frac{(h_{i+1} - h_i)}{[2(r_i - r_{i+1})]} + (j-1)\frac{(h_{i+1} - h_i)}{(r_i - r_{i+1})} \quad (2)$$

where:

H_{ij} - total height estimated at the age tij, m;

t_{ij} - age of the tree associated with the ring j in the i-th disk, years;

n - total age of the tree, years;

r_i - number of growth rings in the i-th disk;

j - each growth ring counted from the pith, for each i-th disc taken from from the tree, j = (1,2, ..., ri);

i - number of the disk, bottom-up direction;

h_i - height of the i-th sampled disk, that is, the sum of all lengths below the i-th disk, m.

$$V = \frac{g_1 + g_2}{2}(l_1) \quad (3)$$

where:

v - section volume, m³;

g_1 - cross-sectional area 1, m²;

g_2 - cross-sectional area 2, m²;

l1 - section length, m.

Based on the values of diameter, height and volume for each age, the estimates of current annual increments (CAI) and the mean annual increments (MAI) were calculated for each sampled tree using the Eqs. 4 and 5.

$$ICA = Y(t+1) - Y(t) \quad (4)$$

where:

CAI - current annual increment;

t - time, years;

Y - size of the variable considered.

$$y = \frac{a}{(1+e^{b-cx})^{1/d}} \quad (5)$$

where:

MAI - mean annual increment;

t_0 - age from time zero, years;

Y_t - size of the variable considered.

Growth behavior in each age and descriptive statistics, namely, arithmetic mean, standard deviation and coefficient of variation of the data, were used to describe the growth in terms of diameter, height and volume of *S. amazonicum*. Comparison of growth between the two plantations was performed by analysis of variance (ANOVA) and Tukey test.

To describe the increase in volume, statistical nonlinear regression models were fitted in the R environment for statistical computing (R Development Core Team, 2011), as shown in Eq. 6 to 9. The criteria used for selection of the best equations were the adjusted determination coefficient and the standard error of the estimate.

- Richards:

$$y = \frac{a}{(1+e^{b-cx})^{1/d}} \quad (6)$$

- Weibull

$$y = a - be^{-cx^d} \quad (7)$$

- Logistic

$$y = \frac{a}{(1+be^{-cx})} \quad (8)$$

- Ratkowsky

$$y = \frac{a}{[1+\exp(b-cx)]} \quad (9)$$

where:

y - dependent variable;

x - independent variable;

a, b, c, d - parameters of the equations.

3. RESULTS AND DISCUSSION

Table 1 shows the growth data of *S. amazonicum*recovered by the ANATRO, and the comparison of parameters by the Tukey test.

There were statistically significant differences only for the variable height ($p < 0.001$) from the eighth year onwards, as shown in Table 1. Plantation one (1) showed greater heights in relation to plantation two (2). However, there was no significant difference for the variable volume. Until the eighth year, trees of plantation one (1) had reached 64.5% of their total growth while in plantation two (2), this value was 57.2%.

The coefficient of variation (CV) was 7.3 to 29.6%, which shows heterogeneity among growing trees and between plantations. CAI and MAI for the variables diameter and height for the two plantations was higher in the first years. The same was observed by Cordeiro (2007), where paricá showed decreasing increment in DBH as the age increased. This reduction was not observed for CAI and MAI of volume, which was greater from the seventh year onwards, and this is due to increased cross-sectional area in older ages.

Hoffman et al. (2011) observed diameters of 19.2, 20.1 and 21.3 cm to the fifth, sixth and seventh years and height of 21.2, 21.8 and 23.1 m for this ages, respectively, in plantations of *S. amazonicum* in the municipality of Paragominas, PA. In a study of Cordeiro (2007), *S. amazonicum* intercropped with other species in the municipality of Aurora do Pará showed an increase in diameter of 5.51 cm year^{-1} and 4 m in height at 1.5 years. Ribeiro et al. (2004) noted diameter increments of 5.1 cm year^{-1} for diameters at two years and eight months in agroforestry systems in Barcarena, PA. Santos (2012) found a diameter of

Table 1. Growth assessment of *S. amazonicum* in plantations one (1) and two (2) (DBH = average diameter; CAI = current annual increment; MAI = mean annual increment; Ht = height; Vol = volume).
Tabela 1. Avaliação de crescimento da espécie *S. amazonicum* nos plantios um (1) e dois (2) (DAP = diâmetro médio; ICA = incremento corrente anual; IMA= incremento médio anual; Ht= altura; Vol= volume).

	Age	DBH (cm)	CAI (cm)	MAI (cm)	Ht (m)	CAI (Ht) (m)	MAI (Ht) (m)	Vol (m³)	CAI (Vol) (m³)	MAI (Vol) (m³)
Plantation 1	1	3.73ns	3.73	3.73	4.80ns	4.80	4.80	0.0067ns	0.0067	0.0067
	2	6.03ns	2.30	3.01	8.55ns	3.75	4.28	0.0195ns	0.0128	0.0098
	3	8.53ns	2.50	2.84	11.88ns	3.33	3.96	0.0410ns	0.0215	0.0137
	4	10.56ns	2.04	2.64	15.05ns	3.18	3.76	0.0686ns	0.0276	0.0172
	5	12.53ns	1.96	2.51	17.58ns	2.53	3.52	0.1077ns	0.0391	0.0215
	6	14.80ns	2.28	2.47	19.33ns	1.75	3.22	0.1548ns	0.0470	0.0258
	7	17.01ns	2.21	2.43	21.65ns	2.33	3.09	0.2449ns	0.0902	0.0350
	8	19.45ns	2.44	2.43	23.18**	1.53	2.90	0.3411ns	0.0962	0.0426
	9	21.60ns	2.15	2.40	24.85**	1.68	2.76	0.4343ns	0.0932	0.0483
	10	23.20ns	1.60	2.32	26.08**	1.23	2.61	0.5224ns	0.0880	0.0522
	11	24.66ns	1.46	2.24	27.55**	1.48	2.50	0.6043ns	0.0819	0.0549
	12	25.73ns	1.06	2.14	28.28**	0.72	2.36	0.6845ns	0.0802	0.0570
	13	27.10ns	1.38	2.08	28.85**	0.58	2.22	0.7675ns	0.0830	0.0590
	14	28.30ns	1.20	2.02	29.05**	0.20	2.08	0.8750ns	0.1075	0.0625
	15	29.08ns	0.77	1.94	29.11**	0.06	1.94	0.9550ns	0.0800	0.0637
	16	30.14ns	1.06	1.88	29.18**	0.06	1.82	1.0437ns	0.0888	0.0652
Plantation 2	1	3.08ns	3.08	3.08	4.60ns	4.60	4.60	0.0023ns	0.0023	0.0023
	2	4.90ns	1.83	2.45	6.95ns	3.48	3.48	0.0088ns	0.0064	0.0044
	3	6.89ns	1.99	2.30	9.63ns	3.21	3.21	0.0212ns	0.0124	0.0071
	4	8.53ns	1.64	2.13	11.38ns	2.84	2.84	0.0384ns	0.0172	0.0096
	5	11.23ns	2.70	2.25	13.70ns	2.74	2.74	0.0668ns	0.0284	0.0134
	6	13.05ns	1.83	2.18	15.80ns	2.63	2.63	0.1024ns	0.0356	0.0171
	7	15.80ns	2.75	2.26	17.33ns	2.48	2.48	0.1622ns	0.0598	0.0232
	8	18.40ns	2.60	2.30	18.35**	2.29	2.29	0.2401ns	0.0780	0.0300
	9	21.10ns	2.70	2.34	19.43**	2.16	2.16	0.3464ns	0.1063	0.0385
	10	23.58ns	2.48	2.36	20.10**	2.01	2.01	0.4652ns	0.1188	0.0465
	11	25.70ns	2.13	2.34	21.28**	1.93	1.93	0.5745ns	0.1093	0.0522
	12	26.98ns	1.28	2.25	21.85**	1.82	1.82	0.6664ns	0.0919	0.0555
	13	28.30ns	1.33	2.18	22.65**	1.74	1.74	0.7473ns	0.0809	0.0575
	14	29.94ns	1.64	2.14	23.10**	1.65	1.65	0.8308ns	0.0835	0.0593
	15	31.00ns	1.06	2.07	23.55**	1.57	1.57	0.9002ns	0.0694	0.0600
	16	32.18ns	1.18	2.01	23.88**	1.49	1.49	0.9633ns	0.0632	0.0602

Where: ns (not significant), * (significant at 5% probability) and ** (significant at 1% probability), presenting statistical differences between plantations for the same age according to Tukey test.

15.6 cm at the fifth year ofS. *amazonicum* trees planted in a spacing of 3 x 2 m in the municipalities of Dom Eliseu and Paragominas in Pará. Although the results of the present study carried out in Mato Grosso state are below those reported in literature, yet they are considered satisfactory because this is a native species with few silvicultural advances and improvement when compared to exotic cultures such as those of the genera *Pinus* and *Eucalyptus.* However, on another perspective, it is also necessary to consider the efforts to improve the kind of growing conditions present in the state of Mato Grosso.

Studies on growth must consider various aspects such as age, genetic material, spacing and fertilizers. Significant differences may arise from these aspects. The evaluation of the origins of *S. amazonicum* carried out by Tonini et al. (2005) showed that, at the fifth year, the species had MAI of 3.3; 3.2 and 3.5 cm for the three studied origins (Acre, Pará and Rondônia), respectively. Quisen et al. (1999) concluded that *S. amazonicum* has strong initial growth, reaching 15 years with 55 cm (DBH), a performance that is higher than that found in the present study. Viégas et al. (2007) observed in their research in Garrafão do Norte, PA, with samples of this species at the age of one year and ten months that the phosphate fertilizer significantly influenced DBH. Silvicultural treatments such as fertilization with phosphate and choosing the best genetic material for each planting should be used to improve the development of DBH.

Plantation one (1) showed better results, although not statistically significant, for the variables height and volume (Figure 1b and 1c). Figure 1c shows the mean values for volume in both areas and shows that plantation one (1) had always higher performance when compared to plantation two (2). Although higher diametric production was observed in plantation two (2) from the ninth year onwards, this behavior is due, in part, to the fact that plantation one (1) received fertilization during the first three years while plantation two (2) received it only in the first year, and also due to the greater spacing (12 m²) adopted in plantation one (1).

As shown in Figure 2, at no time during the period analyzed in this study MAI and CAI volume curves intercepted each other, indicating that plantations have not yet reached the point of maximum production. However, it is possible to observe a sharp reduction in CAI from the 10th year onwards in plantation two (2), indicating that competition began to influence growth and that this plantation approaches its maximum production, which may occur at the age of 17. (Figure 2b).

Table 2 shows the statistical results of the tested models to estimate volume according to age for the studied plantations.

The use of biometric models in population studies is frequent in different situations, either to the description of their parameters, or to the indirect assessment of the effects on the environment where the population is, or to prognosis, especially through simulation (SILVA, 2012). Statistical results

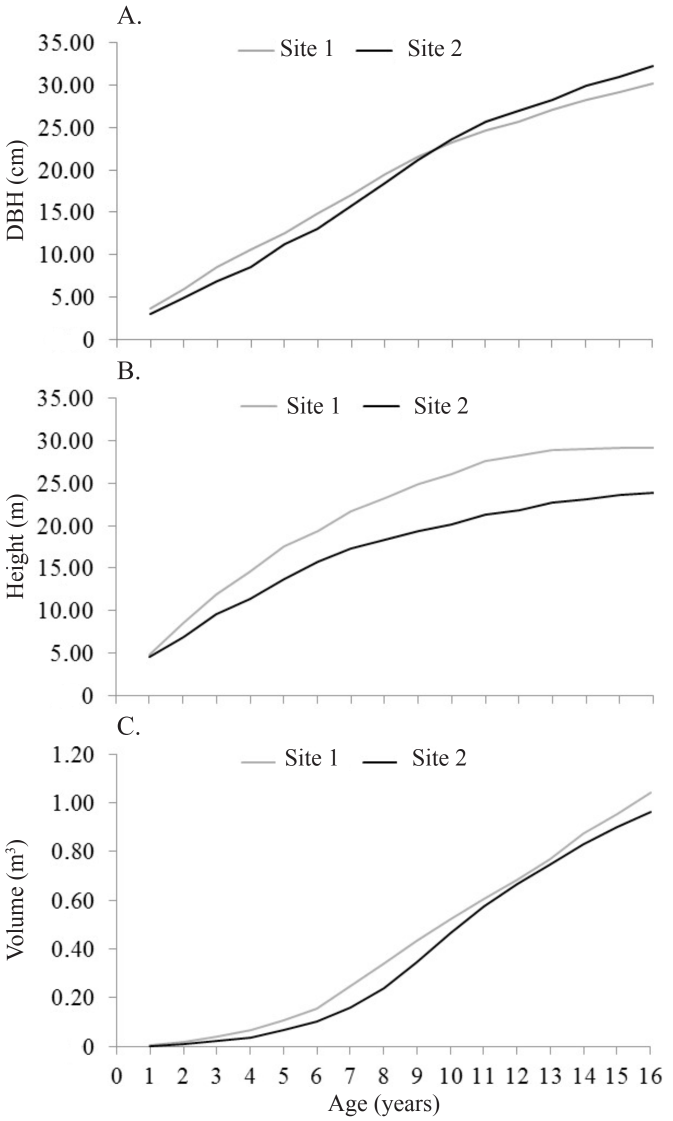

Figure 1. Growth curves of diameter (a) total height (b) and volume (c) according to age of *S. amazonicum* in the state of Mato Grosso.
Figura 1. Curvas de crescimento em diâmetro (a), altura total (b) e volume (c) em função da idade para *S. amazonicum* no estado de Mato Grosso.

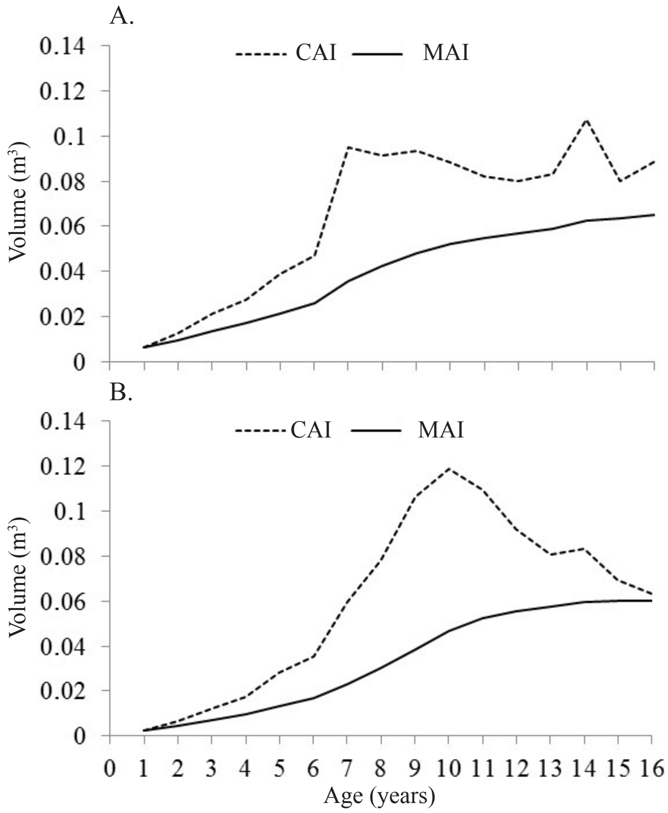

Figure 2. Current and mean annual volume increment in plantation one (1) "a" and plantation two (2) "b" for *S. amazonicum* in the state of Mato Grosso.
Figura 2. Incremento corrente e médio anual volumétrico no plantio um (1) "a" e plantio dois (2) "b" para *S. amazonicum* no estado de Mato Grosso.

presented in Table 2 show that, in general, models had good accuracy. According to the statistics of the model (coefficient of determination and standard error of the estimate), the best fitted models were Richards' and the Logistic model, respectively. However, the best results were found for plantation two (2).

According to statistics (R^2 and Syx), other models are not recommended for the representation of volume production curves for the species investigated in the studied plantations. Santos (2012) concluded that the logistic model, as in the present study, was the most appropriate to estimate volume values and to describe growth curves of these variables for *S. amazonicum*. Richards' model has been extensively used for various plantations, especially in the south of the country, where it is reported as the best for modeling the growth and production of *Pinus* sp. forests. (SELLE et al., 1994); *Eucalyptus* sp. (MIGUEL et al., 2011), and *Mimosa scabrella* (bracatinga) of the region of Curitiba (MACHADO et al., 1997). The performance of this model is due to its asymptotic characteristic which is able to accurately describe growth stages (juvenile, mature and senescent).

The application of these techniques to data from commercial plantations, located so as to cover a range of site and age classes and even management options such as planting density, thinning

Table 2. Statistical coefficients and parameters of adjustment of models for *S. amazonicum* in the state of Mato Grosso.
Tabela 2. Coeficientes e parâmetros estatísticos do ajuste dos modelos para *S. amazonicum* no estado de Mato Grosso.

	Model	Parameters				Syx	Syx%	R_{aj}^2
		a	b	c	d			
Plantation 1	Richards	1.5230	-3.79763	0.17106	0.00369	0.31966	31.85	0.65544
	Weibull	1.41071	1.41279	0.00222	2.3032	0.32966	32.85	0.63544
	Logistic	1.15629	51.0091	0.3665	-	0.31775	31.66	0.65343
	Ratkowsky	1.15628	3.93202	0.36625	-	0.33775	33.65	0.64343
Plantation 2	Richards	1.12649	1.95380	0.3043	0.3198	0.16910	16.85	0.81128
	Weibull	1.01992	1.01550	0.00031	3.2689	0.17035	16.97	0.80103
	Logistic	1.01470	129.71023	0.46247	-	0.16810	16.75	0.81750
	Ratkowsky	1.01471	4.86529	0.46247	-	0.17987	17.92	0.80010

Where: a, b, c and d = coefficients of the equation; Syx = standard error of the estimate; R^2 = Coefficient of determination.

and conveyances, among other criteria, are the following steps to take. Continuous simulation of the management of populations supported by technical and economic decision criteria is extremely important because it allows the optimization of forest production.

4. CONCLUSIONS

In the state of Mato Grosso, the species *Schizolobium amazonicum* showed lower growth than in other states like Pará, Acre and Rondônia, and this may be related in part to a higher level of selection of the progeny grown in other states of the Amazon, or the cultural and silvicultural treatments applied.

According to the growth in volume, the two analyzed plantations have not reached the technical cutting age (intersection of CAI x MAI curves), and, therefore, have not reached their maximum production. Both plantations have similar growth in volume and adjusted models show satisfactory results to estimate the volume according to age.

5. ACKNOWLEDGEMENTS

We would like to thank Madenorte Agroindustrial Company S/A and the Research, Assistance and Rural Extension Company S.A. of Mato Grosso- EMPAER-MT for allowing the realization of this study.

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