



Dendrometric evaluation of a clonal population of *Tectona grandis* in forest-livestock system

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ABSTRACT: Production of *Tectona grandis* (teak) in integrated systems with livestock or agriculture demonstrates high potential of financial return. However, studies on the development of teak are still scarce, especially in the northern region state of Mato Grosso. In this study we sought to evaluate dendrometric variables of a clonal population of teak in a forest-livestock integration system (LFIS), during a period of 53 months in the city of Alta Floresta, Mato Grosso, Brazil. For this purpose, three installments were sampled, a total of 360 individuals, and for each the diameter was measured at 1.3 meters from the base so as to calculate the total volume, the current annual increment (CAI) and mean annual increment (MAI), and five adjusted regression models. The Hoerl model provided the highest adjusted coefficient of determination (R^2_{aj}), lowest standard error of estimate (S_{yx}), coefficient of variation (CV %), and from this the growth curves were developed. Clonal stands of teakin the forest-livestock system presented increases in DBH, height and volume were superior in relation to other scientific studies with teak, indicating their viability in integrated systems with pastures in the region.

Key words: Growth, model, LFIS, teak.

Levantamento dendrométrico de um povoamento clonal de *Tectona grandis*, em sistema silvipastoril

RESUMO: A produção de madeira de *Tectona grandis* (teca) em sistemas integrados com pecuária ou agricultura demonstra alta perspectiva de retorno financeiro. Entretanto, estudos sobre o desenvolvimento da teca ainda são escassos, principalmente na região norte de Mato Grosso. O objetivo do trabalho foi avaliar o crescimento das variáveis dendrométricas de um povoamento clonal de teca, em um sistema silvipastoril (iPF), ao longo de 53 meses, no município de Alta Floresta-MT, Brasil. Para isso, foram amostradas três parcelas, totalizando 360 indivíduos, sendo que em cada indivíduo foi mensurado o diâmetro a 1,3 m do solo e altura total. Em seguida realizou-se o cálculo do volume. Para descrever o crescimento da variável diâmetro, altura total e volume foi realizado o ajuste através de cinco modelos matemáticos que expressam o crescimento ao longo do tempo. Posteriormente, foram calculados o incremento corrente anual (ICA) e incremento médio anual (IMA). O modelo de Hoerl apresentou melhores resultados de R^2_{aj} , obteve menores valores para o erro padrão de estimativa (S_{yx}) e para o CV%, com isso, foi selecionado para a elaboração das curvas de crescimento. O povoamento clonal de teca no iPF apresentou incremento em DAP, Altura e volume foram superiores em relação a outros estudos científicos com teca, indicando sua viabilidade em sistemas integrados com pastagens na região.

Palavras-chave: modelos de crescimento, Sistema iPF, teca.

INTRODUCTION

In Mato Grosso cattle ranching has expanded greatly in recent decades (SILVA et al. 2016). However, it is noted that 100 million hectares of Brazilian pastures showed some degree of degradation (NIERI et al., 2018).

The forest-livestock integration system (LFIS) stands out among the various types of systems, with inclusion of tree components providing animal comfort and improving soil fertility, resulting

in greater productivity and profitability for rural producers due to the production timber products and animal protein in the same area (PAULA et al., 2013). Study of the silvicultural behavior of the species inserted in the LFIS is relevant, especially forest species with potentially high-value timber (NIERI et al., 2017). The *Tectona grandis* L. F. (teak) species from the tropical monsoon forests of Southeast Asia (MORETTI et al., 2014) shows potential for reforestation and the production of wood for sawmills (SILVA et al., 2016).

In the state of Mato Grosso, it was estimated that more than 67.329 hectares were planted, an increase of 14.67% between the years of 2009 and 2012 (MORETTI et al., 2014), and usually implanted in mosaics, mixed with native forest, agriculture and pasture (FAMATO, 2013).

The growth of teak species varies according to local soil and climatic conditions, mainly as a function of precipitation, relative humidity and temperature (SINHA et al., 2011). There is; therefore, a need for scientific studies in the state of Mato Grosso for silvicultural development of teak and its integration with agricultural crops, growth monitoring and production (MEDEIROS et al., 2015).

Schuhli and Paludzyszyn Filho (2010) affirmed that there is a special interest in Brazil on studies of the potential for recovery of degraded areas, productivity in silvicultural, livestock and/or agriculture integration systems, the participation of legal reserve areas on the production process and the feasibility of teak production for small producers.

Cultivation of teak in the extreme north of Mato Grosso can be considered an alternative of stimulating potential for homogeneous forest cultivations and in consortium with pastures, characterized as an advantage for differentiated use of the soil in the forest-livestock integrated production system. The objective of the present study was to evaluate the development of the diameter at breast height (DBH), height and volume of a clonal stand of teak in LFIS, for 53 months, via different mathematical models and evaluated the mean annual increase (MAI) and current annual increase (CAI) of clonal seedlings in plantations integrated with pastures.

MATERIALS AND METHODS

The studied site is located in an area belonging to the company Forest Bacaeri, with geographical coordinates of 56° 52' 44" W and 09° 58' 17" S, and elevation of 230 m. The climate according to the Köppen classification is Aw, tropical rainy season with high rainfall (2.200 to 2.550 mm), characterized by a rainy tropical climate in which the mean annual temperature varies from 23 to 25 °C and with well-defined seasons: summer rains and winter droughts (ALVARES et al., 2013).

The soil of the experimental area is classified according to Embrapa (2013) as red-yellow latosol dystrophic (Oxisol) with a sandy clay texture, presenting the following chemical characterization at the depth of 0-0.20 m (Table 1).

Table 1 - Chemical and physical properties of the experimental soil.

Characteristic	Value
pH (CaCl ₂)	4.8
OM* (g dm ⁻³)	24.0
P -Mehlich-1 (mg dm ⁻³)	1.9
K- (mmol _(c) dm ⁻³)	1.8
H ⁺ +Al ³⁺ (mmol _(c) dm ⁻³)	40.5
Ca ²⁺ (mmol _(c) dm ⁻³)	20.8
Mg ²⁺ (mmol _(c) dm ⁻³)	5.1
Al ³⁺ (mmol _(c) dm ⁻³)	1.8
CEC** (mmol _(c) dm ⁻³)	67.9
SB*** (%)	43.5
Sand fraction (g kg ⁻¹)	554
Silt fraction (g kg ⁻¹)	86
Clay fraction (g kg ⁻¹)	360

Where: *OM = organic matter **CEC = Cation Exchange Capacity ***SB = Base of saturation.

The experimental design was a randomized block design (RBD) in the planting lines of clonal seedlings of *Tectona grandis* L. F. in a forest-livestock system, tested five growth models, with four replications. The area of study corresponds to 2.7 ha, inserted in an area of 45 ha, composed of pasture (*Urochloa brizantha* cv. Marandu) and teak, in LFIS and spacing of 25 x 3 m. Clonal seedlings (Clone A1) were obtained from the clonal garden. After the plants completed one year of growth, three plots with 120 individuals each were selected in the growing area, totaling 360 trees.

Evaluations began in November 2009 and were conducted through May 2013, totaling seven measurements. For each individual, the circumference at breast height (CBH) was measured at 1.30 meters from the ground using a tape measure, for subsequent conversion to diameter at breast height (DBH). For the measurements of height metallic rulers of 12 m, graduated in meters, were used. Because the population was young, the rigorous cubage was not determined to establish the form factor. Thus, the artificial form factor was adopted as reported by DRESCHER et al. (2014) for teak (Table 2).

With the data on diameter (cm), height (m) and volume (m³) as a function of age, growth models were adjusted for each of the dendrometric variables, whose models are presented in table 3.

Five mathematical models were adjusted by linear regression (Minimum Squares Method).

Table 2 - Factor of artificial form according to the age of the settlement of the Forest Bacaeri. (DRESCHER et al., 2014).

Age (months)	Form actor
12	0.621
17	0.610
23	0.599
31	0.557
37	0.532
46	0.496
53	0.488

Models were adjusted for spacing, utilizing the R software (R Core Team, 2015), and the variables were selected via a stepwise function. Selection of the best model initially confirmed the lowest relative standard error of the estimate (Syx %), the largest adjusted coefficient of determination (R^2Aj), the graphic distribution of the bias-free residuals (E%) and the normality of the residuals, by using the Shapiro–Wilk test at $p < 0.05$ significance.

RESULTS AND DISCUSSIONS

The diameter estimates as a function of age demonstrated that the equations present statistical parameter values for the adjusted coefficient of determination (R^2Aj) higher than 0.90. Standard error values of the estimates (Syx) were less than 15.5% (Table 4). The equations adjusted well to the observed data, positive describing the growth in diameter of the teak stand.

The equation $\ln(\text{DBH}) = 2.590 - 19.775 \times (1/t) + 0.120 (\text{Lnt})$, adjusted by the Hoerl model

Table 3 - Models adjusted for diameter, total height and volume growth as a function of age of the Forest Bacaeri.

Equation	Mathematical Model	Author
1	$\ln(y) = \beta_0 + \beta_1 * \text{Lnt} + \beta_2 * \text{ln}^2 t$	Backman
2	$\ln(y) = \beta_0 + \beta_1 * (1 t)$	Schumacker
3	$\ln(y) = \beta_0 + \beta_1 * (1 t) + \beta_2 * \text{Lnt}$	Hoerl
4	$\ln(y) = \beta_0 + \beta_1 * \text{Lnt} + \beta_2 * t$	Gram
5	$\ln(y) = \beta_0 + \beta_1 * t + \beta_2 * t^2 + \beta_3 * t^3$	Moissev

Where: Ln = natural or neperian logarithm, ($\beta_0, \beta_1, \beta_2, \beta_3$) = coefficients to be estimated, t = age (months), y (DBH, height, volume).

showed better precision and progressive increase in DBH (Figure 1B), presented the lowest standard error (14.49%) and demonstrated a higher value for the adjusted coefficient of determination (0.914), and the graphical distribution of the residues showed that the regression coefficients were significant and there was no bias (Figure 1A).

Behavior of residual distribution of heights (H) presented the same trend as DBH, where the Hoerl model showed a better residual distribution and a better adjustment to growth in height as a function of age (Figure 1C). The Hoerl model for description of the height growth curve demonstrated the accelerated growth of teak in the early years of development (Figure 1D).

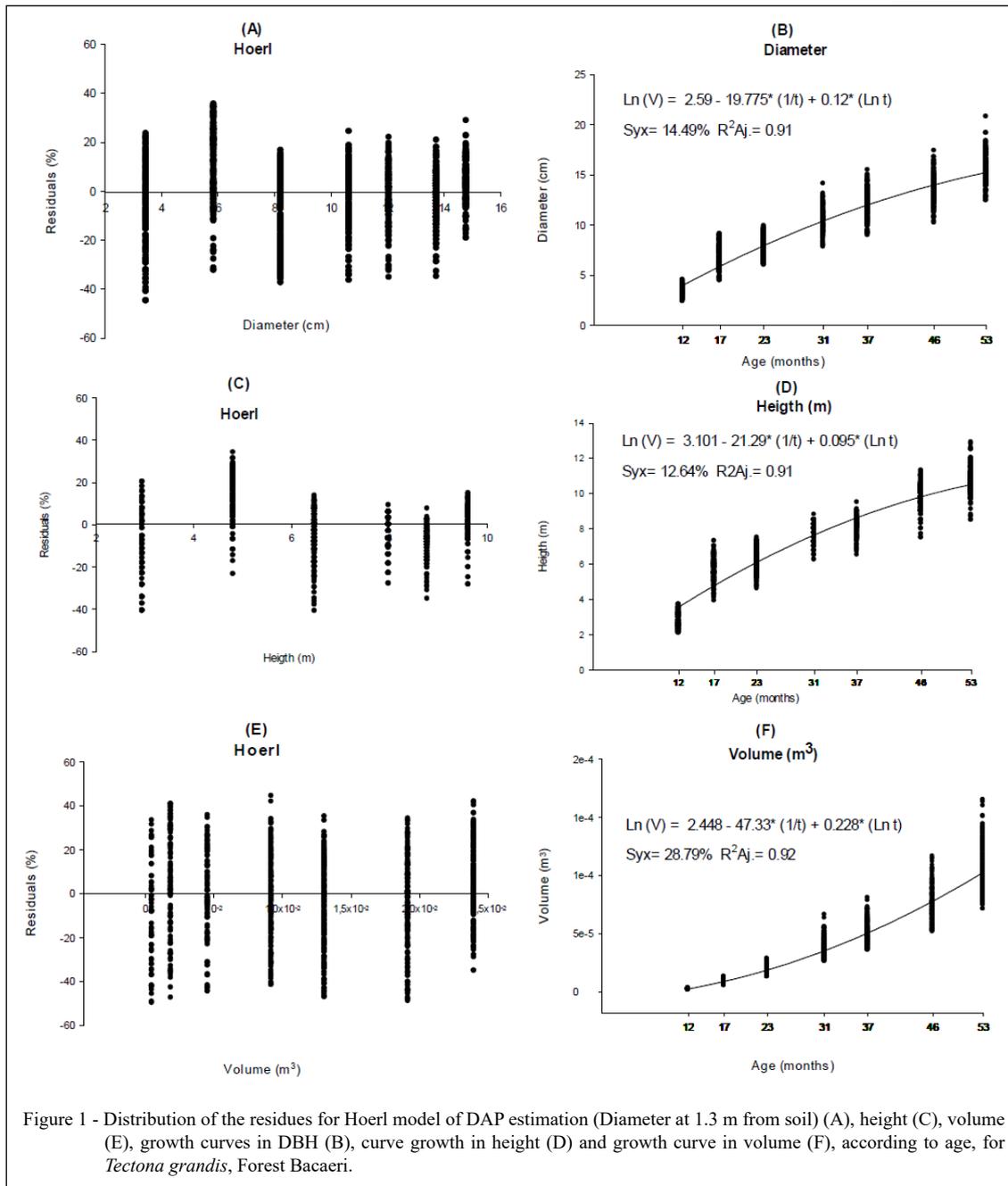
Analyzing table 5 and figure 1C it can be observed that the Hoerl equation more adequately represented height growth, since it presents a smaller standard error (12.64%), higher value of $R^2Aj = 0.9084$ and homogeneous distribution of residues.

Estimates of the total volume as a function of age showed similarities with the estimates of

Table 4 - Statistical parameters of the equations tested to adjust the growth in diameter as a function of age of the Forest Bacaeri.

Equation	-----Coefficients-----				R^2Aj	Syx	CV%	F
	β_0	β_1	β_2	β_3				
Schumacker	3.10	-22.52	-	-	0.913	0.145	1.45	12951*
Backman	-4.88	3.41	-0.38	-	0.910	0.148	1.47	6177*
Hoerl	2.59	-19.77	0.120	-	0.914	0.144	1.44	6521*
Gram	-2.52	1.65	-0.02	-	0.906	0.152	1.51	5861*
Moissev	-0.76	0.22	5×10^{-4}	4×10^{-4}	0.908	0.149	1.49	4034*

Where: R^2Aj = adjusted coefficient of determination; Syx = standard error of the estimate; CV% = coefficient of variation in %; F = value of F of the analysis of variance; $\beta_0, \beta_1, \beta_2, \beta_3$ = coefficients, * Significant at 5% probability.



diameter and height, where the equation of the Hoerl model presented a higher adjusted coefficient of determination (0.928) and for the standard error of the estimate the lowest value (28.9), as well as homogeneous dispersion of residues (Table 6 and Figure 1E). The initial behavior growth of teak height is rapid. Considering that is a heliophyte species, requiring a high demand for light, intolerant

to shade, this behavior indicates good adaptation of the species to the region.

Distribution of the volume residues showed similarity with the distribution of diameter and height residues, and the Hoerl model stood out as presenting the best statistical parameter and adequate residual dispersion (Figure 1E). The pattern presented coincides with the typical pattern of tree growth,

Table 5 - Statistical parameters of the equations tested to adjust the growth in height as a function of age of the Forest Bacaeri.

Equation	-----Coefficients-----				R ² Aj	Syx	CV%	F
	β_0	β_1	β_2	β_3				
Schumacker	2.68	-19.05	-	-	0.90	0.126	1.71	12072.5*
Backman	-4.80	3.36	-0.39	-	0.89	0.133	1.80	5424.4*
Hoerl	3.10	-21.29	-0.09	-	0.90	0.126	1.71	6072.5*
Gram	-2.28	1.50	-0.02	-	0.88	0.138	1.88	4922.7*
Moissev	-0.91	0.23	6×10^{-3}	5×10^{-4}	0.90	0.132	1.79	3676.3*

Where: R²Aj = adjusted coefficient of determination; Syx = standard error of the estimate; CV% = coefficient of variation in %; F = value of F of the analysis of variance; β_0 , β_1 , β_2 , β_3 = coefficients, * Significant at 5% probability.

which is sigmoidal, where initially the volume growth curve presents a slow increase, but the volumetric growth curve has an exponential increase (Figure 1F). The clonal stands of teak in LFIS in the Forest Bacaeri showed an increase in characteristic height of the juvenile phase of the species, demonstrating rapid growth during the study period.

There was an increase in the assessed period to the variable diameter, height and volume, and their respective ICA and IMA (Table 7). Growth in DBH at 5 years of age in the city of Nossa Senhora do Livramento-MT, Brazil was 13.9 cm (CALDEIRA & OLIVEIRA, 2008), a result that was lower than the 14.8 cm evaluated at 53 months. The mean annual increment (MAI) in diameter at 46 months of age presented a value of 3.587 cm year⁻¹, a superior result presented to that obtained by Silva, Silva and Miranda (2014), who reported 2.694 cm year⁻¹ in 48 months in the region of Alta Floresta-MT.

The mean annual increase in height was 2.849 m year⁻¹ at 37 months of age, followed by a constant reduction (Table 7). This result was superior

to that observed by Pelissari, Caldeira and Drescher (2013), who verified a value of 2.63 m year⁻¹ at 36 months and also that of TONINI et al. (2009), who obtained a value of 2.341 m year⁻¹, at 36 months of age. According to these authors, the low increase in height may have been influenced by the genetic (seminal) material used and inadequate soil management. It is still important to point out that the decrease of the average heights in the densified stands (ARAÚJO et al., 2014), as a consequence of the level of competition between individuals (BERGER et al., 2002), thus justifying superior results in forest-livestock systems.

The current annual increment (CAI) in height presented an initial increase, with a value of 1.86 m year⁻¹, and at 53 months the value was 0.467 m year⁻¹, there was a marked reduction in its CAI for height. The CAI value at 37 months was of 0.791 m year⁻¹, higher than the result of MACEDO et al. (2005), who presented values of 0.611 m year⁻¹ at 36 months of age.

The mean annual increment (MAI) and current annual increment (CAI) presented volume

Table 6 - Statistical parameters of the equations tested to adjust the growth in volume as a function of age of the Forest Bacaeri.

Equation	-----Coefficients-----				R ² Aj	Syx	CV%	F
	β_0	β_1	β_2	β_3				
Schumacker	-1.46	-52.8	-	-	0.92	0.297	59.32	12446.1*
Backman	-19.88	7.8	-0.87	-	0.91	0.299	61.06	5792.2*
Hoerl	-2.44	-47.3	0,22	-	0.92	0.287	57.11	6256.6*
Gram	-14.23	3.7	-0.05	-	0.91	0.308	63.05	5400.3*
Moissev	-10.57	0.5	-0.013	1×10^{-4}	0.91	0.296	60.74	3941.1*

Where: R²Aj = adjusted coefficient of determination; Syx = standard error of the estimate; CV% = coefficient of variation in %; F = value of F of the analysis of variance; β_0 , β_1 , β_2 , β_3 = coefficients, * Significant at 5% probability.

Table 7 - Growth diameter (DBH), height (H) and volume of *Tectona grandis*, Forest Bacaeri.

Age	DBH	MAI	CAI	H	MAI	CAI	V	MAI	CAI
months	cm			m			m ³		
12	3.461	3.461	-	2.956	2.956	-	0.002	0.002	-
17	5.869	4.136	2.398	4.816	3.399	1.860	0.008	0.006	0.006
23	8.230	4.294	2.371	6.483	3.383	1.670	0.014	0.008	0.006
31	10.650	4.123	2.419	7.997	3.095	1.513	0.027	0.011	0.013
37	12.064	3.913	1.414	8.786	2.849	0.791	0.037	0.012	0.011
46	13.749	3.587	1.685	9.627	2.511	0.841	0.048	0.013	0.010
53	14.803	3.352	1.053	10.09	2.285	0.467	0.107	0.024	0.059

values of 0.006 m³ year⁻¹ at 17 months, followed by a progressive increase up to 53 months of age. In Monte Dourado, PA, Brazil, and MAI of 0.008 m³ year⁻¹ was obtained at 36 months of age (ROSSI et al., 2011), and a study by MACEDO et al. (2005), the mean volume at 36 months was 0.0012 m³ year⁻¹ (Table 7). In the city of Nossa Senhora do Livramento-MT, Brazil, Pelissari, Caldeira and Drescher (2013) obtained an MAI at 36 months of 0.0103 m³ year⁻¹, and the MAI value at 37 months in the present study was 0.012 m³ year⁻¹, a higher value of the mean annual increase for volume growth, indicating good development of the plants in the place of study.

Parameters of growth, height and volume were superior in relation to scientific studies of dendrometric survey with specie, it is justified by use of clonal seedlings of teak and the spatial arrangement that contributed to the reduction of competition between plants and also as edaphoclimatic conditions of the place that favor the development of plants.

CONCLUSION

The model of Hoerl was which presented better residual distribution and better adjustment of growth in diameter, height and volume to teak in forest-livestock integrated production system. The observed results of MAI and CAI of diameter, height and volume were superior in relation to other scientific studies with teak, indicating their viability in integrated systems with pastures in the region.

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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