Ciência Florestal, Santa Maria, v. 23, n. 3, p. 461-470, jul.-set., 2013
ISSN 0103-9954

LINEAR MIXED MODEL TO DESCRIBE THE BASAL AREA INCREMENT FOR INDIVUDUAL CEDRO (*Cedrela odorata* L.)TREES IN OCCIDENTAL AMAZON, BRAZIL

MODELO LINEAR MISTO PARA O INCREMENTO EM ÁREA BASAL DE ÁRVORES INDIVIDUAIS DE CEDRO (*Cedrela odorata* L.) NA AMAZÔNIA OCIDENTAL, BRASIL

Thiago Augusto da Cunha[1] César Augusto Guimarães Finger[2] Paulo Renato Schneider[3]

ABSTRACT

Reliable growth data from trees are important to establish a rational forest management. Characteristics from trees, like the size, crown architecture and competition indices have been used to mathematically describe the increment efficiently when associated with them. However, the precise role of these effects in the growth-modeling destined to tropical trees needs to be further studied. Here it is reconstructed the basal area increment (BAI) of individual *Cedrela odorata* trees, sampled at Amazon forest, to develop a growth-model using potential-predictors like: (1) classical tree size; (2) morphometric data; (3) competition and (4) social position including liana loads. Despite the large variation in tree size and growth, we observed that these kinds of predictor variables described well the BAI in level of individual tree. The fitted mixed model achieve a high efficiency (R^2=92.7 %) and predicted 3-years BAI over bark for trees of *Cedrela odorata* ranging from 10 to 110 cm at diameter at breast height. Tree height, steam slenderness and crown formal demonstrated high influence in the BAI growth model and explaining most of the growth variance (Partial R^2=87.2%). Competition variables had negative influence on the BAI, however, explained about 7% of the total variation. The introduction of a random parameter on the regressions model (mixed modelprocedure) has demonstrated a better significance approach to the data observed and showed more realistic predictions than the fixed model.

Key words: Mixed model; generalized last-squares; tree-morphometry; competition indices.

RESUMO

Dados confiáveis de crescimento de árvores são importantes para o manejo florestal. Características da árvore como o tamanho, arquitetura da copa e índices de competição, associados aos dados de crescimento da árvore são utilizados com freqüência como variáveis preditoras. Entretanto, a efetividade desse tipo de variáveis na modelagem do crescimento de árvores tropicais é pouco conhecida. Nesta pesquisa, reconstruímos o incremento periódico em área basal (IPG) de árvores individuais de*Cedrela odorata*,amostradas na floresta Amazônica, para desenvolver um modelo de crescimento utilizando preditores potenciais como: (1) tamanho da árvore; (2) dados morfométricos; (3) competição; (4) posição sociológica e infestação de lianas na copa. Apesar da alta variação no tamanho da árvore e no crescimento, observamos que estas variáveis descrevem muito bem o IPG em nível de árvore individual. O modelo misto ajustado apresentou alta eficiência (R^2=92.7 %) e estimou para três anos o IPG com casca em árvores com diâmetro a altura do peito variando desde 10 a 110 cm. A altura total, grau de esbelteza e formal de copa demonstraram elevada influência no crescimento em área basal e explicaram a maior parte da variação no crescimento (R^2 parcial=87.2%). Variáveis de competição apresentaram influência negativa no IPG, entretanto, explicaram cerca de 7% da

---

[1] Engenheiro Florestal, Dr., Professor Adjunto do Centro de Ciências Biológicas e Naturais, Universidade Federal do Acre, Rodovia BR-364, Km 4, Distrito Industrial, CEP 69915-900, Rio Branco (AC). dacunha@ufac.br

[2] Engenheiro Florestal, Dr., Professor Associado do Departamento de Ciências Florestais, Centro de Ciências Rurais, Universidade Federal de Santa Maria, Av. Roraima, 1000,CEP 97105-900, Santa Maria (RS). caesar.finger@gmail.com

[3] Engenheiro Florestal, Dr., Professor Titular do Departamento de Ciências Florestais, Centro de Ciências Rurais, Universidade Federal de Santa Maria, Av. Roraima, 1000, CEP 97105-900, Santa Maria (RS). paulors@smail.ufsm.br

Recebido para publicação em 5/07/2010 e aceito em 3/05/2012

variação total. A introdução do parâmetro aleatório no modelo de regressão (modelo misto) conduziu a uma melhor aproximação aos dados observados (acurácia) com predição mais realística quando comparado ao modelo fixo.

Palavras-chave: modelo misto; mínimos quadrados generalizados; morfometria da árvore; índice de competição.

INTRODUCTION

There is a considerable interest in promoting timber sustainability as strategy for conservation and maintaining production in the Amazon rainforest. It assumes minimal information, the tree growth patterns of the component species or at least those species considered important (VANCLAY, 1994), combined into forest management practices. The modeling of tree growth are an important tool providing tangible forest management actions, like a practical selection of tree species for timber production, estimate of the cutting cycle and prescribed silvicultural treatments (SILVA, 2002), furthermore, it can contribute to the forest management decision because it provides a stand development by forecasts (SÁNCHEZ-GONZALES et al., 2006) contributing to the administrative decision-making.

In order to model the tree growth, the forest managers identified sources of variability that needs to be collected for model improvement (FOX et al., 2001). Predictor variables that express tree-size, competitive status and attribute of the stand are considered the starting point for modeling tree growth (WYKOFF, 1990; CHOI et al., 2001). Each observation from the same unit sample tends to be highly correlated and conferring to the growth data a hierarchical structure with lack of independence between the measures (WEST, 1995) as a result of repeated measurements or simultaneous measurements (stem analysis) at the same unit sample (tree). Consequently, the use of ordinary least-square (OLS) violates supposes and maybe can include variables that are not significant in the model.

Then, the development of general models that overcomes correlated data had been evaluated from different perspectives. The use of mixed models is an alternative and its use has recently increased for modeling stand development instead of individual tree level (BUDHATHOKI et al., 2008). The mixed model allows the parameter vector varies randomly between each scenario that causes variability (e.g. among trees). Thus, the regression coefficients are divided into a fixed part, which defines a pattern of response common average for the population evaluated, and random components, which includes specific parameters for each unit sample, assuming that it affects the variability of the observed data (LAPPI, 1997). Under these circumstances, the main objective of this investigation is modeling a mixed model to describe the basal area increment (BAI) of individual Cedro trees (*Cedrela odorata*) using tree predictor variables and competition indices. This model is useful to understand what kind of variables affects the growth rate and can be used for access management needs for applied research purposes. We then compare the performance of the mixed growth model with a fixed growth model.

MATERIAL AND METHODS

Study area

The data were collected based on a Plan for Sustainable Forest Management (PFS) over 325 ha, licensed by Instituto Brasileiro do Meio Ambiente (IBAMA) and located approximately 49 km northeast of Rio Branco, the capital of Acre State, Brazil. The study area had smooth topography cut by some streams (HOLDRIDGE, 1978) and an annual rainfall of 1.900 mm, which was concentrated mainly between September and May (IMAC, 1991) during a period known as the "Amazonian winter". The average temperature was approximately 23 °C (ZEE, 2000). Dominant vegetation consisted of large trees, forming three or more layers of canopies between 25 and 35 meters of height, with emergent trees reaching 45 meters and an average basal area (DBH > 20 cm) of 16 m^2 ha^{-1} and 115 trees $hectare^{-1}$ (ZEE, 2000).

Data collection

For the previous PFS inventory, 62 out of 114 Cedro trees were randomly sampled, showing a DBH distribution ranging from 10 cm to 110 cm. The radial incrementof each individual tree was obtained from partial steam analysis by removing two perpendicular cores, with approximately 100 mm in length, taken at 1.3 m (DBH) with a standard 5-mm increment borer. In trees with tabular roots (buttresses), the cores were extracted above them to prevent the over- or underestimation of growth rates (METCALF et al., 2008). Cores were visually cross-dated (STOKES and SMILEY, 1996), and ring increments were measured with 0.01 mm of accuracy using Lintab, a linear table, (Frank Rinn S.A., Heidelberg, Germany) and the computer compatible tree ring software TSAP-Win (RINN, 2003). Next, we reconstructed the recent growth by averaging the last three rings (representing the period from 2005-2008) for each Cedro tree. The periodic basal area increment (BAI) for the *ith* tree under bark was calculated by Equation 1:

$$BAI_i = (\pi/4) \times (DBH^2_t - DBH^2_{t-n})$$

Where n=3 years.

This interval was chosen to maintain approximately constant the temporal correlation between the current state of the tree (i.e. tree architecture and status of competition) and the tree growth. The use of basal area increment instead of diameter increment as the dependent variable was arbitrary. Both variables do not cause differences in accuracy when equations of diameter increment or basal area are used (WEST, 1995) since any difference in the adjustment is attributed to the structure of the error (VANCLAY, 1995). In each individual Cedro trees a range of potential predictor variables were sampled and calculated to modeling the BAI. These variables are described below:

1. Tree size variables: diameter at breast height (DBH_i), cm; total height (H_i), m; crown length (Cl_i), m, i.e. the vertical distance between the uppermost and the bottom leaves; crown width (CW_i) m, derived by eight measurements of crown radius made in the cardinal and intercardinal directions (ALDER and SYNNOTT, 1992) and the area of crown projection (CPJ_i), m^2.
2. Tree-morphometric variables: stem slenderness calculated as a ratio between H_i and DBH_i (HD_i); Saliency Index calculated by relationship between CD_i and DBH_i, (SI_i) and crown shape ratio (CSR*i*=crown width/crown length) (ASSMANN, 1970; DURLO and DENARDI, 1998; STERBA et al., 2002).
3. Tree-quality variables: here we evaluated the crown position (CP_i) and liana load on the crown (LL_i). Based on a Dawkins illumination index (DAWKINS, 1963), the CP in each Cedro tree was categorized into one of the following: (1) dominant (full overhead and side light); (2) co-dominant (full overhead light); (3) intermediated (some overhead or side light); and (4) suppressed (no direct light). Likewise, the LL_i was assessed by assigning values 1 for trees free of lianas, 2 for the presence of lianas on the bole and crown (at the same time with up to 50% of the tree covered by lianas) and 3 for the severe form with more than 75 % of presence of lianas on the bole and crown. Moreover, five DBH classes (DC_i) with range of 20 cm were created. The lowest limit increased from 10 to 30 cm, and the upper limit that corresponds to larger trees increased from 90 to 110 cm. These effects were represented as discrete variables (*Dummy* variables) like:

Diametric Class	Crown Position	Liana Load
$D1 = \left\{\begin{matrix} 1, if DC = 1 \\ 0, Otherwise \end{matrix}\right\}$	$D6 = \left\{\begin{matrix} 1, if CP = 1 \\ 0, Otherwise \end{matrix}\right\}$	$D10 = \left\{\begin{matrix} 1, if LL = 1 \\ 0, Otherwise \end{matrix}\right\}$
$D2 = \left\{\begin{matrix} 1, if DC = 2 \\ 0, Otherwise \end{matrix}\right\}$	$D7 = \left\{\begin{matrix} 1, if CP = 2 \\ 0, Otherwise \end{matrix}\right\}$	$D11 = \left\{\begin{matrix} 1, if LL = 2 \\ 0, Otherwise \end{matrix}\right\}$
$D3 = \left\{\begin{matrix} 1, if DC = 3 \\ 0, Otherwise \end{matrix}\right\}$	$D8 = \left\{\begin{matrix} 1, if CP = 3 \\ 0, Otherwise \end{matrix}\right\}$	$D12 = \left\{\begin{matrix} 1, if LL = 3 \\ 0, Otherwise \end{matrix}\right\}$
$D4 = \left\{\begin{matrix} 1, if DC = 4 \\ 0, Otherwise \end{matrix}\right\}$	$D9 = \left\{\begin{matrix} 1, if CP = 4 \\ 0, Otherwise \end{matrix}\right\}$	
$D5 = \left\{\begin{matrix} 1, if DC = 5 \\ 0, Otherwise \end{matrix}\right\}$		

Considering the nearest neighbor tree as a competitor for a subject tree (ESBER, 2003), three competition indices, at plot level, also were calculated to measure the status of competition and use as predictor variable. The spatial dependence index was calculated for each subject tree by:

Hegyi Index (e.g. DAVIES and POMMERENING, 2008): ;

$$Hegyi_i = \sum_{i=1}^{n} \left[\left(\frac{DBH_j}{DBH_i} \right) \times \frac{1}{HDist_{ij}} \right]$$

Vertical Competition Index (e.g. MITSUDA et al., 2002): .

$$VCI_i = \sum_{j=1}^{n} \left[tang^{-1} \times \left(\frac{\Delta H}{HDist_{ij}} \right) \right]$$

And using a non-spatial dependence index by:

Glover and Hool Index (e.g. FOX et al., 2008): .

$$Glover_i = \sum_{j=1}^{n} \left(\frac{DBH_j^2}{DBH_i^2} \right)$$

Where: i is the subject tree (Cedro); j is neighbor (consider as a competitor) tree; n is the number of neighbors; $\overline{\mathrm{DBH}}^2_{\mathrm{i}}$ is the arithmetic mean diameter at breast height of all competitor trees in the plot (cm); $\mathrm{HDist}_{\mathrm{ij}}$ is the horizontal distance between trees i and j.

Statistical analysis

Owing the tree growth data have a nested stochastic structure, a linear mixed model (Model 2) was constructed with the same data set from Cunha (2009). This model included a tree as a random parameter and was fitted by generalized least-squares (GLS) techniques. The mixed model provide a more flexible and accurate framework for managing this kind of structure for the growth data (WEST, 1995).

$$BAI_i^{0.23} = \beta_0 + \beta_1 H + \beta_2 HD + \beta_3 D1Glover + \beta_4 D3Hegyi + \beta_5 D5Cl + \beta_6 Formal + \beta_7 D12CPJ + \varepsilon_i$$

$$\therefore \beta_0 = \gamma_0 + u_i$$

Where: $D1Glover_i$ and $D3Hegyi_i$ are the competition by tree competitor that infers at tree-sample of DBH class 1 and DBH class 3, respectively; $D5Cl_i$=crown length of the DBH class 5; $D6formal_i$= crown formal at dominant crown position and $D12CPJ_i$ is the crown projection of the tree influenced by high level of liana load; $\beta_0, \ldots, \beta_7$ = model parameters; ε_i is the residual error within each *ith* tree $\sim N(0,\sigma^2)$; γ_0 = the mean intercept across trees; u_i = random parameter designing the specific amounts by which *ith* tree (unit sample) deviates from these mean. The random parameter estimates are free to vary across individuals trees and it assumed that $u_i \sim N(0,\tau_0)$ and cov $(u_i,\varepsilon_i) = 0$;0.23= constant estimated by Box-Cox transformation methodology (e.g. GONÇALVES and MEDDAHI, 2010) to reduce the variances.

The use of Box-Cox transformation is justified because the skewness is smaller than when use the log transformation in a finite sample. A random intercept was included in the model 2 (parameterized by Cunha, 2009) to covering some variance not considered in usually fixed model to yield better predictions. The vector of fixed effects (β) was estimated by GLS and the variance components (τ_0,σ^2_e) were estimated simultaneous by Restricted Maximum Likelihood (REML) method. The random parameter vector was calculated by the expression 3:

$$u_i = DZ^T(R+ZDZ^T)^{-1}e$$

Where: u_i = vector of Best Linear Unbiased Predictor (BLUP) for random components, acting at tree level; D= block diagonal matrix; Z= the design matrix for the random components specific to the additional observations. R=the estimated matrix for the residual variance; e= vector with dimension corresponded to a number of observations; whose components are the values of residuals.

To obtain the BLUP a data job in SAS System was developed using MIXED and GLIMMIX Procedure in the SAS/STAT (2007). A covariance structure type of *Variance Component* was specified to account the correlation between observations.

Validation tests based on observed and predicted data were calculated to determine the accuracy of the model (e.g. VANCLAY and SKOVSGAARD, 1997), so the means (Bias, cm²; Bias, %), the standard error of estimates (S_{yx}, cm²; S_{yx}, %) and the modeling efficiency (E) were achieved using the statistics shown in Table 1. Standard residuals were plotted against the predicted basal area increment (CALAMA and MONTERO, 2005). To evaluate the mixed model, an information-theoretic approach, using the Akaike information criterion (AIC) and Bayesian information criteria (BIC) also was calculated. A variance explained by each group of predictors variables selected to fit the mixed model was accessed (e.g. MONSERUD and STERBA, 1996).

RESULTS AND DISCUSSION

Fitted equation

After statistical testing(exclusion of outliers and influential points), a final model showed significance for fixed regression parameters and random parameterat 0.001level. A mixed linear equation to estimate the BAI for *Cedrela odorata* was expressed in the Equation 4:

$$BAI_i^{0.23} = 2.6612(0.2436)+0.04487(0.0057) H-0.01343(0.0021)HD-0.56454(0.1707) D1Glover-1.0587(0.2190)D3Hegyi-0.02069(0.00593) D5Cl+0.1925(0.04602)D6Formal-0.00109(0.000307) D12CPJ+u_i+\varepsilon_i$$

$u_i \sim N(0;\ 0.02618)$

$\varepsilon_i \sim N(0;\ 0.005210)$

It is indicated in bracketsthe approximated

TABLE 1: Criteria to evaluate the performance of the fixed and mixed growth model.
TABELA 1: Modelo de critério para avaliação do desempenho do crescimento fixo e misto.

Performance criterion	Symbol	Formula	Ideal
Absolute bias	Bias	$\sum_{i=1}^{n}(obs_i - est_i)/n$	0
Relative bias	Bias%	$\frac{\sum_{i=1}^{n}(obs_i - ets_i)/est_i}{n}$	0
Absolute standard error	S_{yx}	$\left[\frac{\sum_{i=1}^{n}(obs_i - est_i)^2}{n}\right]^{\frac{1}{2}}$	0
Relative standard error	S_{yx}%	$\left[\frac{\sum_{i=1}^{n}(obs_i - est_i/est_i)^2}{n}\right]^{\frac{1}{2}}$	0
Model efficiency or Coefficient of determination	E	$1-\left[\frac{\sum_{i=1}^{n}(obs_i - est_i)^2}{\sum_{i=1}^{n}\left(obs_i - \overline{obs}\right)^2}\right]$	1
Additional criteria also used to evaluate the mixed model:			
Akaike information criterion	AIC	Smaller is better	
Bayesian information criterion	BIC	Smaller is better	

Where: est_i estimated value; obsiobserved value; *n* the number of observations. In all analyses the P values of < 0.05 were considered to denote statistical significance.

standard error for each parameter. The estimated variance component u_i represent the variation between trees ($u_i = 0.02618$) with a larger value than the conditional component ($\varepsilon_i = 0.005210$, for the variance within trees). In addition to this, trees do differ in average BAI rates even after controlling these effects by the predictor variables included in equation 4. Another way of thinking about the source of variation in BAI is to estimate the intra class (trees) correlation (ρ). This correlation was equivalent to $\hat{\rho} = 0.834$, which informs the portion of the total variation in BAI that occur among trees. This also suggests that an OLS analysis of these growth structure data would likely yield misleading results (SINGER, 1998).

TABLE 2: Validation statistics for the fixed and mixed growth models.
TABELA 2: Estatísticas de validação para o modelo de crescimento em área basal fixo.

Performance criteria	Models	
	Fixed[1]	Random[2]
Bias	-8.76283E-16	-2.5773E-16
Bias %	0.00084	0.00013
S_{yx}	0.1732	0.0272
$S_{yx\,\%}$	5.0620	1.5820
E	0.9331	0.9982
AIC		17.60
BIC		21.35

[1]Fitted by Cunha (2009); [2]Equation 4.

Model diagnostics

The fitted statistics for the fixed and mixed model included in Table 2 revealed small values that can be used for future comparisons. When the terms of tendency (Bias) are evaluated, the mixed model (Equation 4) shows a bias quite similar to the fixed model (prediction obtained by the model 2 without random intercept). However, the model efficiencies (E) have increased when consider the variability nested among trees in the Equation 4 because the estimate of the parameters depends on the estimates of the covariance parameters and therefore, the precision of the predicted BAI was better (Figure 1c and 1d) than the fixed model (Figure 1a and 1b) when evaluated the dispersion of the data. Consequently, the 95% prediction intervals (assuming normality of BAI) for the mixed model were narrower than to the fixed model. Furthermore, the residuals obtained by the mixed model showed lower values compared to the obtained by the fixed model (Figure 2).

To analyze the behavior of the mixed model (Equation 4) a panel diagnostic with descriptions of the conditional studentized residual was presented in the Figure 3. It was possible to define a random-

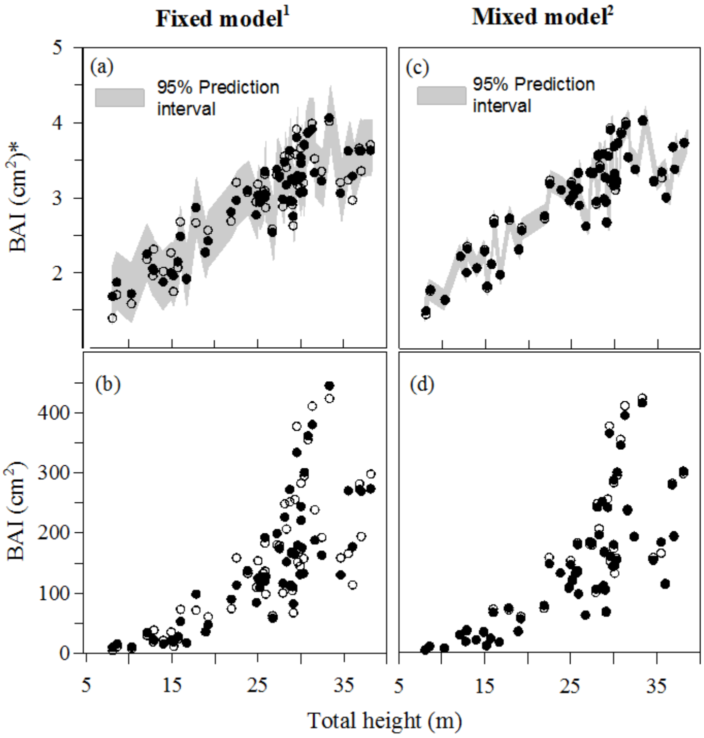

FIGURE 1: Performance of the 3-year basal area increment observed (○) and estimated (●) between 2005 and 2008 by total height for *Cedre laodorata*, in Porto Acre, Acre state, Brazil. *Data weighed with 0.23 power by Box-Cox transformation; ¹parameterized by Cunha (2009); ²Equation 4.

FIGURA 1: Desempenho do incremento em área basal observado (○) e estimado (●) entre os anos de 2005 e 2008 representados em função da altura total para *Cedrela odorata* em Porto Acre, Acre, Brasil. *Dados ponderados a potência 0.23 por transformação Box-Cox; ¹Ajustado por Cunha (2009); ²Equação4.

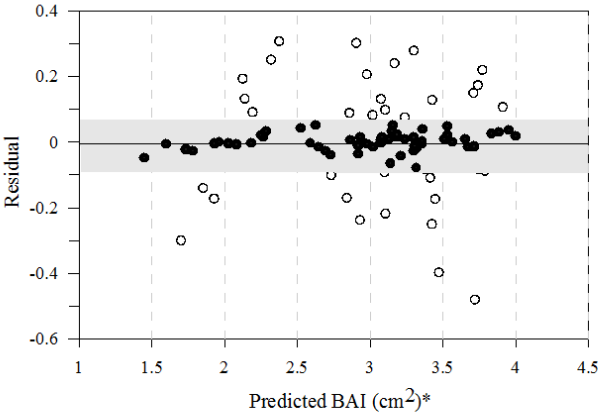

FIGURE 2: Residual pattern distribution yields when fitted the fixed model (○) or the mixed model 4 (grey area) (●).*Data weighed with 0.23 power by Box-Cox transformation.

FIGURA 2: Padrão de distribuição dos resíduos obtidos quando ajustado o modelo fixo (○) ou o modelo misto5 (área cinza) (●).*Dados ponderados àpotência 0.23 por transformação Box-Cox.

ized pattern to the residuals versus predicted value distributions (Figure 3a) and an error distribution supported by the assumption of Gaussian distribution (Figure 3c) reinforced by the QQ Plot (Figure 3b). The box plot shows two outliers, but all of them in the mixed model have a mean of zero (Figure 3d). Moreover, the distribution pattern of the residual error, addition the small evaluation criteria, also suggested a corrected structure of variance-covariance used here (Variance Component)

Effect of the selected predictor variables on BAI

Most of the variation explained by the equation 4 (87.2%) expressed by the partial model efficiency, was due the variables that describe the size of the trees. In a competitive context the variables explained about 6.6% of the total variation in BAI model. As expected, the growth rate showed decrease for trees subjected to greater competition also observed in different sites like in conifers by Wykoff (1990); Quickeet al., (1994); Biging and

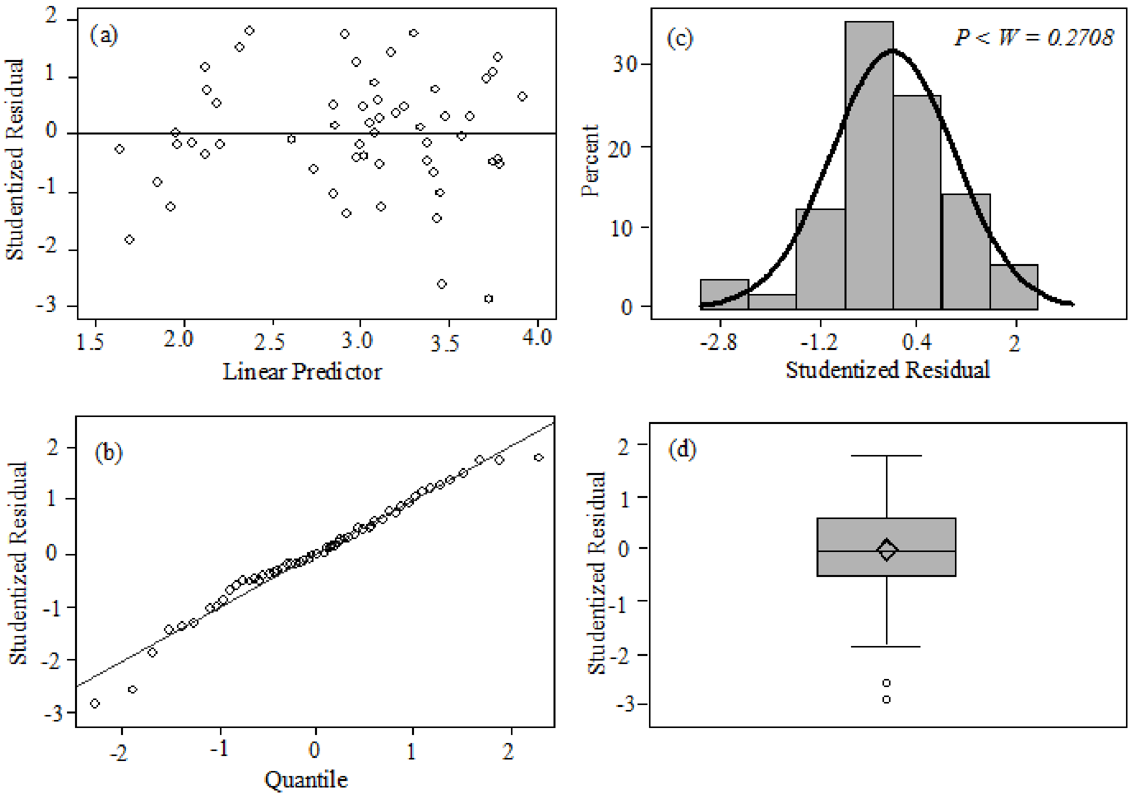

FIGURE 3: Studentized conditional residuals panel to evaluate the adjusted mixed model (Equation 4).
FIGURA 3: Painel de resíduos studentizadoscondicionados para o modelo misto (Equação 4).

Dobbertin, (1995) and for mixed forest stand by Holmes and Reed, (1991); Hasenauer andMonserud (1996); Monserud and Sterba, (1996); Sterbaet al., (2002) in which the diameter and basal area increment decreases with increasing competition. Despite the low contribution of the competition to improve the fit growth equation, this finding was important because it served as regulate of the actual tree size that reflects the past competition.

Trees that have short and wide crowns (i.e. a higher width: crown length ratio) in a dominant position have increasing in BAI growth, as verified by D6 formal variable with a positive regression parameter. Previous research has suggested that of the most important factors influencing tree growth is the amount and distribution of leaf area, as it affects the interception of photosynthetically active radiation (MCCRADY and JOKELA, 1998). For this reason, it follows that as crown width increases, a higher proportion of photosynthate is allocated to the production and maintenance of branches (XIAO et al., 2003).

Unlike other investigations, the fitted growth model demonstrated negative significant effect of the liana load in development the growth in basal area (Equation 4). This effect maybe can be attributed to the method of measurement. Kaineret al*.,* (2006) demonstrated weak or none effect on the diameter growth of tropical and they were attributed to the fact of possibly the foliage of lianas that invades the tree crown can cover leaves and branches to various degrees. Likewise, the severity of liana infestation had no significant effect on diameter growth observed in *Prioriacopaifera* (GRAUEL and PUTZ, 2004). Although, under high liana loads, the effect has decreased the growth but this was restricted to the dominant and co-dominant group of trees (e.g. LADWIG and MEINERS, 2009).

Model forecast

Due the future tree growth is not known with certainty, simulations using deterministic models can lead to seriously biased conclusions and non-optimum forest management (PUKKALA and KANGAS, 1996). This reinforces the advantage when a mixed model is used. Under this consideration, the BAI under bark estimated by the Equation 4 to the next 3 years (Figure 4) was obtained. The behavior of the BAI observed and predicted tells us about the capability of the species to aggregate basal area (i.e. to growth), an important implication to the wood/timber yield. Moreover, considering the full growth-phase (diagonal cross area in Figure 4) was observed between the DBH 50 and 90 cm. In this sense, the technical possibility of execution and the economic viability of the forest management in mixed forest are insured by the good increment (DURLO et al., 2000).

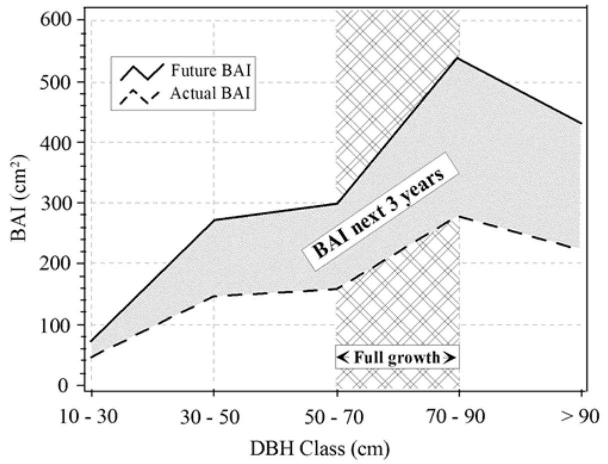

FIGURE 4: Perspective for the BAI growth to the next three years in *Cedrela odorata* in Porto Acre, AC. The hatched area was defined as the increment interval between actual and future BAI predicted by the equation4. The diagonal cross area indicates the class of DBH which has better growth than others.

FIGURA 4: Perspectiva para o BAI nos próximos três anos para *Cedrela odorata* em Porto Acre, AC. A área cinza foi definida pelo intervalo entre o crescimento atual e futuro que foi estimado pelo modelo 4. A área diagonal em cruz indica a classe de diâmetro que apresenta maior crescimento.

CONCLUSION

This research presents a mixed model that can be used to describe and to predict the periodic basal area increment (BAI) of individual *Cedrela odorata* trees using tree size, competition indices and liana loadas independent variables. Owing the large variation of BAI a weight, a constant 0.23, was used. The inclusion of one stochastic component (random intercept) in the model led to reduce the variance and yield predictions more precisely.

REFERENCES

ALDER, D.; SYNNOTT, T. J. **Permanent sample plot techniques for mixed tropical forests**.. Oxford Forestry Institute, 1992. 124 p. (Tropical Forestry Papers; n. 25),

ASSMANN, E. **The Principles of Forest Yield Study**. New York: Pergamon Press, 1970. 506 p.

BIGING, G. S.; DOBBERTIN, M. Evaluation of competition indices in individual tree growth models. **Forest Science**, Bethesda, v. 41, p. 360-377, 1995.

BUDHATHOKI, C. B.; LYNCH, T. B.; GULDIN, J. M. Nonlinear mixed modeling of basal area growth for shortleaf pine. **Forest Ecology and Management**, Amsterdam, v. 255, p. 3440-3446, 2008.

CALAMA, R.; MONTERO, G. Multilevel Linear Mixed Model for Tree Diameter Increment in Stone Pine (*Pinus pinea*): a calibrating approach. **Silva Fennica**, Helsinki, v. 39, p. 37-54, 2005.

CHOI, J. et al. A crown model for simulating long-term stand and gap dynamics in northen hardwood forests. **Forest Ecology and Management**, Amsterdam, v. 152, p. 235-258, 2001.

CUNHA, T. A. **Modelagem do incremento de árvores individuais de** *Cedrela odorata* **L. na floresta amazônica**. 2009. 89 p. Dissertação (Mestrado em Manejo Florestal) - Universidade Federal de Santa Maria, Santa Maria, 2009.

DAVIES, O.; POMMERENING, A. The contribution of structural indices to the modelling of Sitka spruce (*Picea sitchensis*) and birch (*Betula spp.*) crowns. **Forest Ecology and Management**, Amsterdam, v. 256, p. 68-77, 2008.

DAWKINS, H. C. Crown diameters: their relationship to bole diameter in tropical trees. **Commonwealth Forest Review**, Abingdon, v. 42, p. 318-333, 1963.

DURLO, M. A.; DENARDI, L. Morfometría de *Cabralea canjerana*, em mata secundária nativa do Rio Grande do Sul, **Ciência florestal**, Santa Maria, v. 8, p. 55-66, 1998.

DURLO, M. A.; MARCHIORI, J. N. C.; SPATHELF, P. Perspectivas do manejo florestal por árvores singulares, **Ciência e Ambiente**, Santa Maria, v. 20, p. 71-82, 2000.

ESBER, M. L. **Crescimento de** *Cedrela fissilis* **(Vellozo) Mart. como subsídio para o manejo**

florestal sustentado de florestas nativas no Estado do Rio Grande do Sul. 2003. 88 p. Dissertação (Mestrado em Manejo Florestal) - Universidade Federal de Santa Maria, Santa Maria, 2003.

FOX, J. C., BI, H.; ADES, P. K. Modelling spatial dependence in an irregular natural forest, **Silva Fennica**, Helsinki, v. 42, p. 35-48, 2008.

FOX, J. C.; ADES, P. K.; BI, H. Stochastic structure and individual-tree growth models. **Forest Ecology and Management**, Amsterdam, v. 154, p. 261-276, 2001.

GONÇALVES, S.; MEDDAHI, N. Box-Cox transformation for realized volatility. **Journal of Econometrics**. doi: 10.1016/j.jeconom.2010.03.026. 2010.

GRAUEL, W. T.; PUTZ, F. E. Effects of lianas on growth and regeneration of *Prioria copaifera* in Darien, Panama. **Forest Ecology and Management**, Amsterdam, v. 190, p. 99-108, 2004.

HASENAUER, H.; MONSERUD, R. A. A crown ratio model for Austrian forests. **Forest Ecology and management**, Amsterdam, v. 84, p. 49-60, 1996.

HOLDRIDGE, L. R. **Ecología basada en zonas de vida**. San José: Instituto Interamericano de Ciencias Agrícolas, 1978.

HOLMES, M. J.; REED, D. D. Competition indices for mixed species Northern Hardwoods. **Forest Science**, Bethesda, v. 37, p. 1338-1349, 1991.

IMAC – INSTITUTO DE MEIO AMBIENTE DO ACRE. **Atlas geográfico ambiental do Acre**. IMAC, Rio Branco, 1991.

KAINER, K. A. et al. Liana loads and their association with *Bertholletia excelsa* fruit and nut production, diameter growth and crown attributes. **Journal of Tropical Ecology**, Winchelsea, v. 22, p. 147-154, 2006.

LADWIG, L. M.; MEINERS, S. J. Impacts of temperete lianas on tree growth in young deciduous forest. **Forest Ecology and Management**, Amsterdam, v. 259, p. 195-200, 2009.

LAPPI, J. A longitudinal analysis of height/diameter curves. **Forest Science**, Bethesda, v. 43, p. 555-570, 1997.

MCCRADY, R. L.; JOKELA, E. J. Canopy dynamics, light interception, and radiation use efficiency of selected loblolly pine families. **Forest Science**, Bethesda, v. 44, p. 64-72, 1998.

METCALF, C. E.; CLARK, J. S.; CLARK, D. A. Tree growth inference and prediction when the point of measurement changes: modelling around buttresses in tropical forests. **Journal of Tropical Ecology**, Winchelsea, v. 25, p. 1-12, 2008.

MITSUDA, Y.; ITO, S.; TAKATA, K. Effects of competitive and cooperative interaction among neighboring trees on tree growth in a naturally regenerated even-aged *Larix sibirica* Stand in considering height stratification. **Journal of Forest Research**, v. 7, p. 185-191, 2002.

MONSERUD, R.; STERBA, H. A basal area increment model for individual trees growing in even-and-uneven-aged forest stands in Austria. **Forest Ecology and Management**, Amsterdam, v. 80, p. 57-80, 1996.

PUKKALA, T.; KANGAS, J. A method for integrating risk and attitude toward risk into forest planning, **Forest Science**, Bethesda, v. 42, p. 198-205, 1996.

QUICKE, H. E.; MELDAHL, R. S.; KUSH, J. S. Basal area growth of individual trees: a model derived from a regional longleaf pine growth study. **Forest Science,** Bethesda, v. 40, p. 28-42, 1994.

RINN, F. **TSAP-Win, Version 4.64, reference manual: Time Series Analysis and Presentation Dendrochronology and Related Applications.** Heidelberg, 2003. 110 p.

SANCHEZ-GONZALES, M.; DEL RIO, M.; CAÑELLAS, I.; MONTERO, G. Distance independent tree diameter growth model for cork oak stands. **Forest Ecology and Management**, Amsterdam, v. 225, p. 262-270, 2006.

SAS/STAT. SAS Institute Inc., Cary, NC, 2007.

SILVA, R. P. da et al. Diameter increment and growth patterns for individual tree growing in Central Amazon, Brazil. **Forest Ecology and Management**, Amsterdam, v. 166, p. 295-301, 2002.

SINGER, J. Using SAS PROC MIXED to fit multilevel models, Hierarchical models, and Individual growth models. **Journal of Education and Behavioral Statistics**, v. 24, p. 323-355, 1998.

STERBA, H.; BLAB, A.; KATZENSTEINER, K. Adapting an individual tree growth model for Norway Spruce (*Picea abies* L. Karst.) in pure and mixed species stands. **Forest Ecology and Management**, Amsterdam, v. 159, p. 101-110, 2002.

STOKES, M. A., AND T. L. SMILEY. **An Introduction to Tree-Ring Dating**. Tucson: The University of Arizona Press, 1996. p. 73.

VANCLAY, J. K. Growth-models for tropical forests: a synthesis of models and methods. **Forest Science**, Bethesda, v. 41, p. 7-42, 1995.

VANCLAY, J. K. **Modelling Forest Growth and**

Yield. Wallingford: CAB International, 1994. 380 p.

VANCLAY, J. K.; SKOVSGAARD, J. P. Evaluating forest growth models, **Ecological Modeling**, v. 98, p. 1-12, 1997.

WEST, P. W. Application of regression analysis to inventory data with measurements on successive occasions. **Forest Ecology and Management**, Amsterdam, v. 71, p. 227-234, 1995.

WYKOFF, W. R. A basal area increment model for individual conifers in northern Rocky mountains. **Forest Science**, Bethesda, v. 36, p. 1077-1104, 1990.

XIAO, Y.; JOKELA, E. J.,; WHITE, T. L. Species differences in crown structure and growth performance of juvenile loblolly and slash pine. **Forest Ecology and Management**, Amsterdam, v. 174, p. 295-313, 2003.

ZEE – ZONEAMENTO ECOLÓGICO-ECONÔMICO DO ACRE. **Recursos Naturais e Meio Ambiente**. Rio Branco: Secretaria de estado de Ciência, Tecnologia e Meio Ambiente, 2000.