Hypsometric models adjusted for a fragment of Sensu stricto Cerrado in Tocantins, Brazil

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Abstract

Hypsometric models are of great value in order to reduce forest inventory costs. The present work aimed to adjust and evaluate models of hypsometric relation at a Cerrado area in regenerative process, located in the municipality of Gurupi (TO). Ten models, including five linear and five non-linear, were tested. The adjustments were made through R software, for Windows. As criterion for the adjustment of models, the following statistical parameters were used: adjusted coefficient of determination (R²aj.), the residual standard error ($s_{H\hat{H}}$) and the graphical analysis of the residuals; then, the validation of the best adjusted models took place. The best adjustment statistics were for the non--linear models, with emphasis on Gompertz model (model 7), R²aj: 0,489 and:: ($s_{H\hat{H}}$) 17.58%. The models, in general, overestimated the height, reaching up to 40 % more than the real one. As a result, six models were referred for validation: two linear and four non-linear. The best model with prediction was the non-linear Prodan (model 10), which presented better statistical values and graphical variation. It is concluded non-linear models explained more satisfactorily the height-dependent variable.
Keywords: Tree height. Selection. Validation.

Introduction

Due to the current overview of productive restructuring of capital, areas from the Cerrado biome have been the focus regarding investments for implementing agricultural frontiers (INOCÊNCIO, 2010). Therefore, it is of great importance this exploitation considers sustainability since, according to "Instituto Brasileiro de Geografia e Estatística – IBGE" (2004), the Cerrado biome occupies 23.9 % of Brazilian territory. In the state of Tocantins, this biome covers 63.2 % of the area (SEPLAN, 2012).

Therefore, in search of a forest exploitation based on sustainability, it is essential to learn about the characteristics of the area to be managed, which is achieved through an effective forest inventory.

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The forest inventory addresses the quantitative and qualitative definition of individuals in a given area, and the inventory purpose is specified accordingly to the use of the area, which may be forest reserve, wildlife conservation area, commercial reforestation, leisure area and others (RODRIGUES; RODRIGUES, 2012).

In the inventory, the tree diameter measurement is conducted in an uncomplicated and quick way. On the opposite, finding the tree height demands more time, besides the need of using specific instruments (hypsometers), which require some high financial investment. Some adverse situations, especially in native forests, present high density and difficult visualization of the crown and base of the tree (CRECHE, 1996; ANDRADE et al., 2006; SANQUETTA, 2013). As an option for that, there are the hypsometric models; they are able to estimate the height by correlating it with its diameter at breast height (DBH) (SOARES et al., 2006).

In order to reduce the costs of a forest inventory, hypsometric models need only a few trees to have their height measured in the plots, since statistical models process the data and calculate the measurements, resulting in the inventory. To estimate a dependent variable, for example, the total height of the trees, several regression models can be used (SCHNEIDER et al., 2009), and they can be both linear and non-linear. Neto (2012) describes linear models as those which their structure is in the additive form of the parameters. Non-linear models are those whose parameters are aggregated in a non-additive way and can be described as linearizable and non-linearizable (DRAPER; SMITH, 1981).

In this context, it is important to study hypsometric relations in native forests, mainly in Cerrado areas. Therefore, the objective of this study was to evaluate the fit of hypsometric models in an unequal forest stand, characterized as: fragment of Sensu stricto Cerrado in Tocantins.

Material and methods

Area of study and data collection

The study area is located in the southern state of Tocantins, in the municipality of Gurupi, Latitude 11º 43'45"S and Longitude 49º 04' 07" W (FIGURE 1). The climatic classification according to Köppen is Aw (tropical climate with dry season in winter) with annual rainfall around 1.400 mm. (SEPLAN, 2012).

Figure 1. Location of the study area.
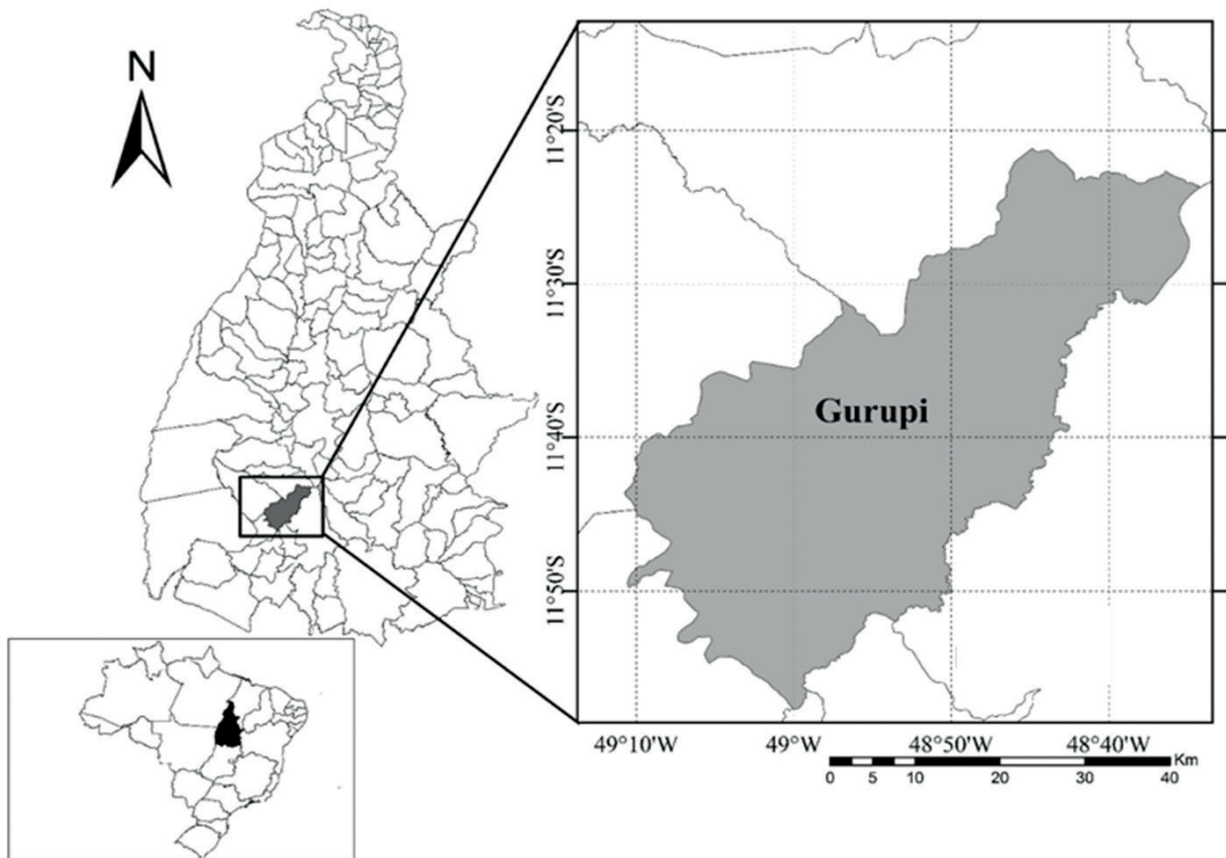
Source: Elaboration of the authors (2016).

The field survey was carried out in a fragment of Cerrado with approximately 7,0 hectares, consisting of vegetation in the process of regeneration in advanced stage. According to a historical survey of the area, it was concluded the site used to be pasture for livestock activity.

In order to collect data for total height and circumference at breast height (CBH), at a point with a radius of 15 meters, three trees were randomly selected and measured, totaling thirty trees to adjust hypsometric models; other thirty trees were used to validate the best fitted hypsometric models (FIGURE 2), thus evaluating the prediction of heights. The term prediction is used to designate the height obtained through an adjusted model in which the tree in question did not participate in its adjustment (BATISTA et al, 2001).

To measure the variables of diameter and height, it was used a metric tape for the CBH (later converted to diameter) and the Suunto hypsometer, respectively. The choice of Suunto hypsometer was due to it being an instrument widely used in the forest area (MAYRINCK et al., 2016; JESUS et al., 2012).

Figure 2. Distribution of points, at which three trees per point, randomly allocated in 7.0 ha of Cerrado, were measured.
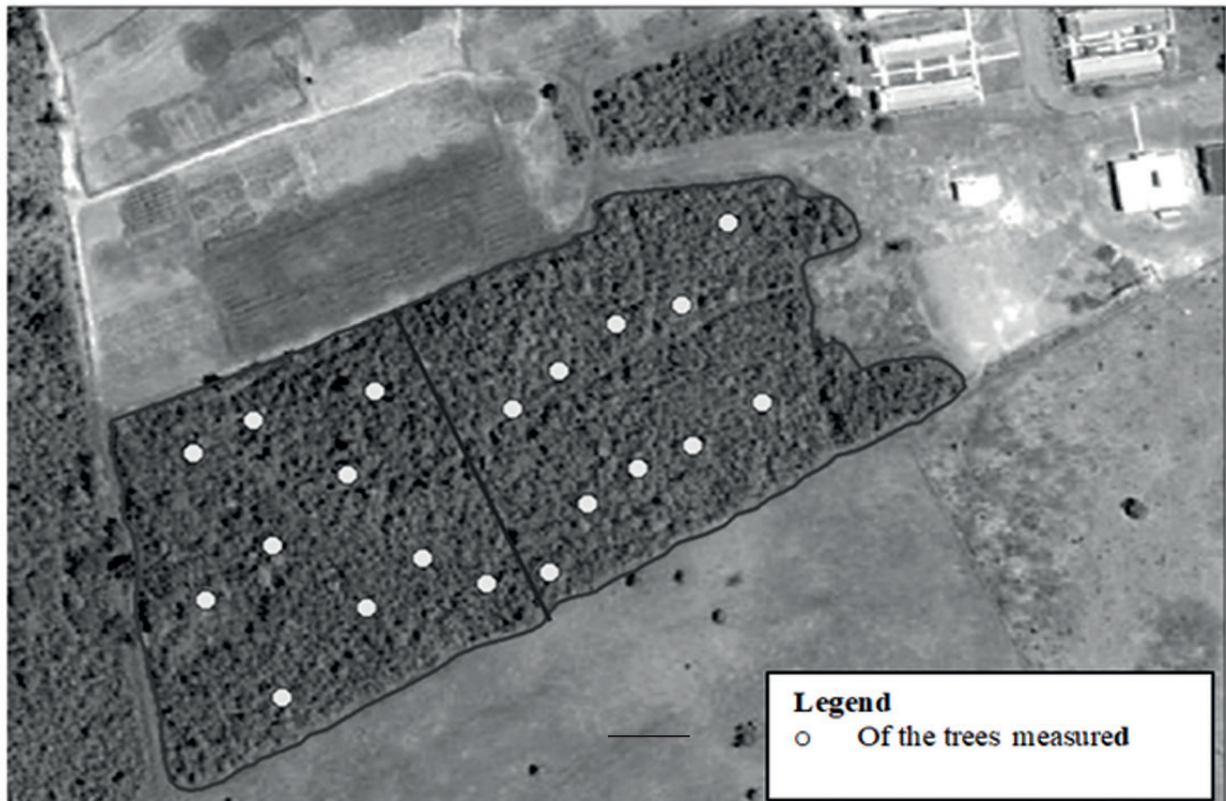
Source: Elaboration of the authors (2016).

Adjusted hypsometric models and evaluation criteria

For the hypsometric relation adjustments, the statistical models presented in Table 1 were used, which are commonly applied when expressing the hypsometric relation of trees in Brazil (VEN-DRUSCOLO et al., 2015; SENA et al., 2015; CURTO et al., 2013). These models, five linear and five non-linear, were adjusted using the software R for Windows, considering only the diameter as an independent variable.

Table 1. Adjusted hypsometric models evaluated for a Cerrado fragment in the southern of Tocantins state.

Nº	MODELS	DENOMINATION
	LINEAR	
1	$H=\beta_0+\beta_1 D+\beta_2 D^2+\varepsilon$	PARABOLIC
2	$\ln(H)=\beta_0+\beta_1 ln(D)+\varepsilon$	STOFFEL
3	$\ln(H)=\beta_0+\beta_1\left(\dfrac{1}{D}\right)+\varepsilon$	CURTIS
4	$H=\beta_0+\beta_1\ln(D)+\varepsilon$	HENRIKSEN
5		AZEVEDO

Nº	MODELS	DENOMINATION
	NON-LINEAR	
6	H=β0(1-β1exp(-β2D))+ε	MONOMOLECULAR
7	H=β0exp	GOMPERTZ
8	$H= \dfrac{β0}{(1+β1exp(-β2D))} +ε$	LOGISTIC
9	H=β0(1-exp(-β1D^β2))+ε	WEIBULL
10	$H= \dfrac{D^2}{(β0+β1D+β2D^2)} +ε$	PRODAN

H = total height; βi = regression parameters; D = diameter at breast height; Ln = neperian logarithm; Exp = exponential; ε = error.

Source: Elaboration of authors (2016).

Subsequently, after adjusting the ten hypsometric models, a preliminary evaluation was performed through the residue analysis and the statistics obtained through Equations 1, 2 and 3:

$$R^2 aj = 1 - \left(\frac{n-1}{n-p}\right)\left(\frac{SSres}{SSt}\right) \tag{1}$$

$$s_{H\hat{h}} = \sqrt{\frac{SSres}{GIres}} \tag{2}$$

$$s_{H\hat{h}}\% = \left(\frac{s_{H\hat{h}}}{\acute{H}}\right) 100 \tag{3}$$

At which:

SSres = sum of squares of residuals, SSt = Sum of total squares, GIres= degrees of freedom of residuals, R²aj = adjusted coefficient of determination, = (S$_{H\hat{h}}$) residual standard error and $\acute{H}$ = average of real heights. Others have already been defined.

In order to define the best hypsometric model, a weighted value of the statistical parameter (WV) scores was used to classify them according to the results of the adjustment statistics, with the lowest WV being the indicator of the best adjustment.

For predicting models, which were previously selected by the criteria described before, it was adopted: absolute error (AE); average of the deviations of the prediction error (ADP); Square root of average error (SRAE%) and coefficient of determination (R²), whose statistics were obtained by Equations 4, 5, 6 and 7:

$$AE = \sum\left|H - \hat{H}\right| \tag{4}$$

$$ADP = \left(\frac{H - \hat{H}}{\frac{H}{n}} \right) 100 \qquad (5)$$

$$SRAE\% = \left(\sqrt{\frac{\Sigma(H - \hat{H})^2}{n}} \right) 100 \qquad (6)$$

$$R^2 = 1 - \left(\frac{SSep}{SSt} \right) \qquad (7)$$

At which:

H = predicted height

n = number of trees

SSep = sum of squares of prediction residues.

Results and discussion

Table 2 presents the results for the estimation of the ten adjusted hypsometric relation models in the study area. It can be noticed the models had very similar behavior, with little variation in the R^2aj and ($s_{H\hat{H}}$) statistics, the R^2aj ranged from 0,362 (MODEL 5) to 0,489 (MODEL 7). For $s_{H\hat{H}}$, the variation was between 17,58 % (MODEL 7) and 20,29 % (MODEL 3). These results of R^2aj and $s_{H\hat{H}\%}$ can be considered satisfactory because it is a native forest of Cerrado, which presents high variation in the relation between height and diameter of the trees.

This implies low correlation between these two variables and, especially, non-elevated R^2aj values, as well as lower results for the other statistics when compared to the adjustment of hypsometric models in planted forest (HESS et al. 2014). In similar studies on hypsometric relation for forest plantations, for example, Azevedo et al. (2011), working with four species (sete-casca – *Samanea tubulosa*; white ipê – *Tabebuia roseo alba*; purple ipê – *Handroanthus impetiginosus*; and yellow ipê – *Handroanthus albus*) native from the plateau (Plateau of Conquest) of Bahia State, found R^2aj superior to 80 %.

Rufino et al. (2010), in his work with an eucalyptus settlement conducted by the regrowth system, obtained values of R^2aj varying from 0.55 to 0.76 %. On the other hand, Hess et al. (2014) adjusted hypsometric relations models for Amazonian Forest species and obtained R^2aj ranging from 0.17 to 0.97 and $s_{H\hat{H}}$ from 0.08 % to 13,2 %. Generally, the complexity of adjustment of hypsometric models in native forest is much higher than in plantations, especially in Cerrado areas (ANDRADE et al. 2015).

Table 2. Adjustment statistics of ten hypsometric models tested in native Cerrado forest

| Models	β0	β1	β2	$s_{H\hat{H}}$%	R^2aj	WV
1	5,882	0,246	-0,0018	17,88	0,470	10
2	1,5071	0,2617	-	17,76	0,459	8
3	2,347	-1,868	-	20,29	0,295	23
4	3,091	2,339	-	18,46	0,436	17
5	1,039	-2,018	-	19,30	0,362	17
6	-1,5663	0.7566	0,0632	17,90	0,451	20
7	18,5930	0,6845	0,0199	17,58	0,489	5
8	489,851	0,009	0,286	18,09	0,444	25
9	15,8434	0,9781	0,0386	17,87	0,471	15
10	14,6869	1,4350	0,0577	17,86	0,472	10

β0, β1 and β2: regression coefficients; $s_{H\hat{H}}$: Standard Error of Percentage Estimation (%); R^2aj: Adjusted Coefficient of Determination; WV: Weighted value of the Scores of the statistical parameters.

Source: Elaboration of authors (2016).

When compared to each other, the five non-linear models are very similar in quality adjustment. It was observed the non-linear models (TABLE 2), in general, had better results, highlighting model 7 with R^2aj of 0,489 and $s_{H\hat{H}}$ of 17.5 %, which resulted in a lower WV value (5 points). The non-linear models are less sensitive to the peculiarities presented in native areas, since the height-diameter curve pattern is strongly linked by the biological characteristics, best represented by the Gompertz biomathematical model (MODEL 7). Therefore, regarding the adjusted models, the models 1, 2, 6, 7, 9 and 10 presented better performance, being the ones previously selected.

Figures 3 and 4 show the residual distribution graphics of the previously selected models. It can be observed the distributions presented similar behavior between models 1 and 2 (linear models), with residual values ranging from 30 to -40% and with the majority of points concentrated between 20 and -20 %. For models 6, 7, 9 and 10 (non-linear models), the values ranged from 25 to -30 %, with a very uniform distribution in this interval, proving to be superior to linear ones. In relation to the meter error is observed a variation of two meters, for more and for less, for all the models. Sena et al. (2015) recommended the Logistic and Gompertz models to establish a hypsometric relation, mainly due to better distribution of residuals.

Figure 3. Percent residuals in DBH function (cm) for six hypsometric previously selected models in a fragment of Cerrado in Tocantins.
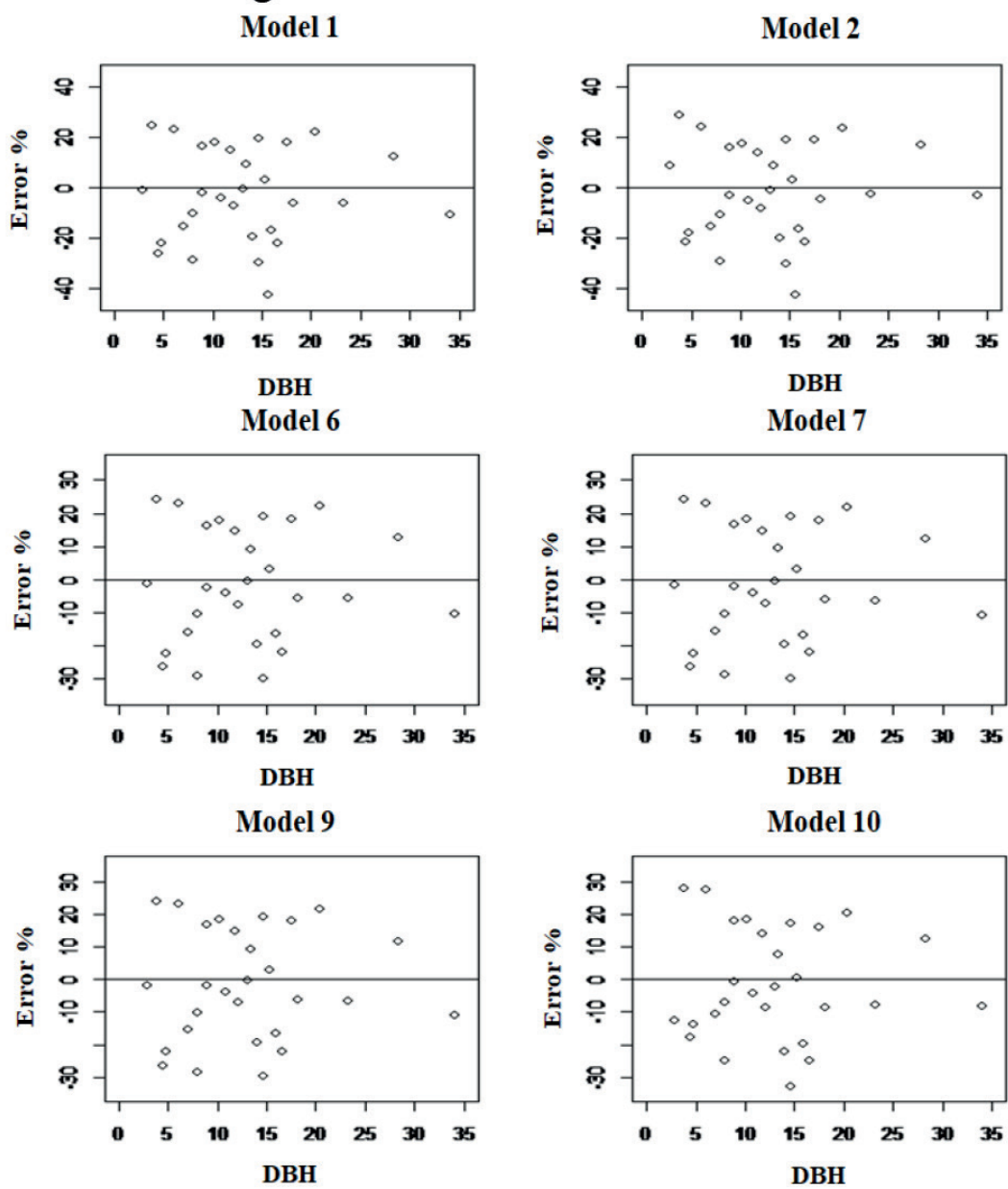
Source: Elaborated by the authors (2016).

Figure 4. Distribution of residues in relation to the estimated height for six hypsometric models previously selected in a fragment of Cerrado in Tocantins.
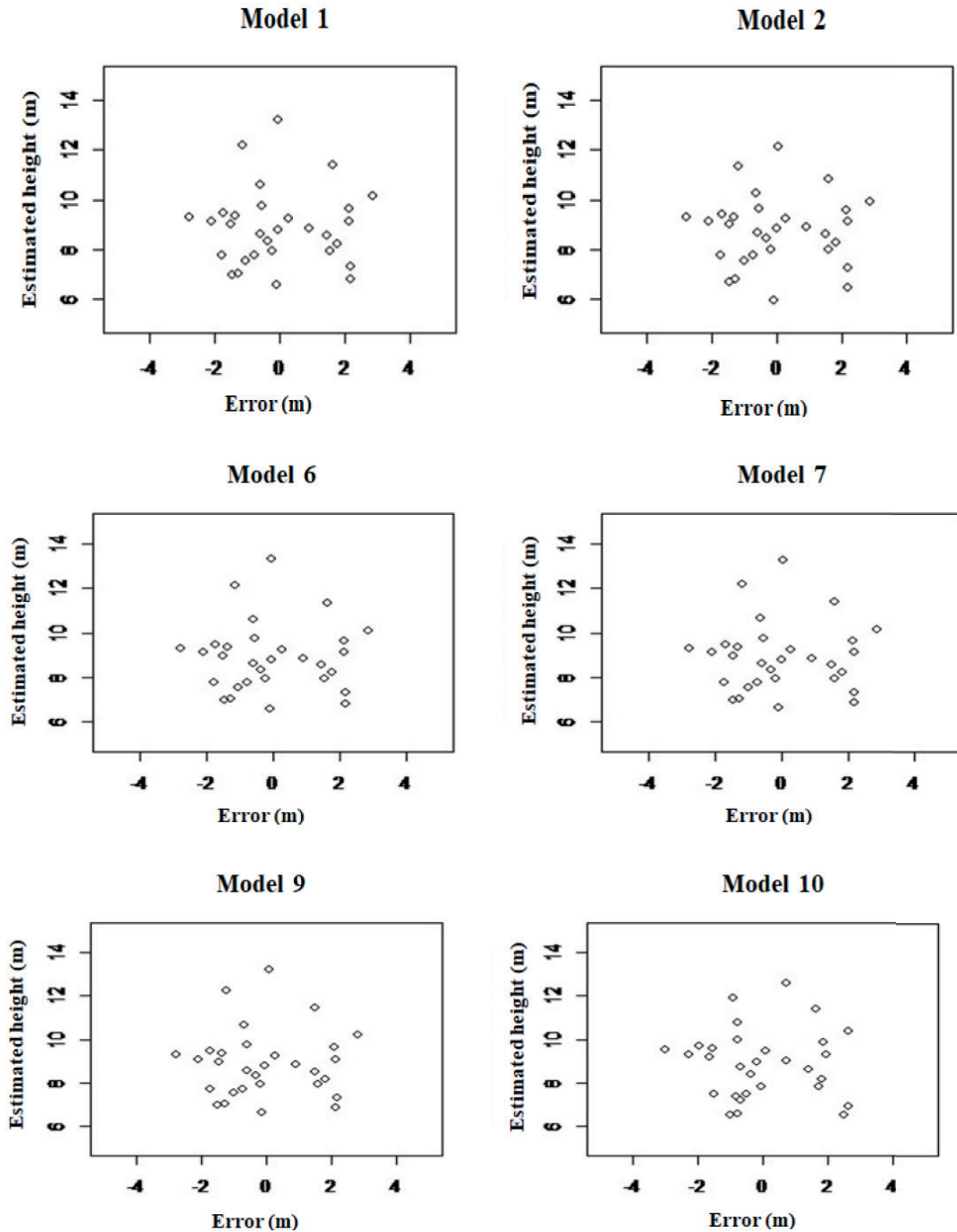
Source: Elaborated by the authors (2016).

Table 3 presents the results for the statistics obtained in the prediction performed with the six previously selected models. Note that there was little variation in the statistical prediction criteria and models 2 and 10 obtained the best values, favoring model 10. In spite of a distribution of residues ranging from 20 % to -60 % among these models, in general, overestimating the height for both models (FIGURE 5), a better behavior was observed for model 10 even though it is not too expressive.

Table 3. Prediction for the models with the best results of R^2, Syx% and dispersion graphic

Model	AE	ADP%	SRAE%	R^2
1	32,376	-13,725	18,30	0,472
2	31,455	-12,676	17,69	0,507
6	32,576	-13,798	18,38	0,468
7	32,436	-13,757	18,33	0,471
9	32,376	-13,663	18,30	0,473
10	28,701	-11,553	16,45	0,574

AE: absolute error; ADP: the average of the deviations of the prediction error in percentage; SRAE%: square root of average error; R^2: coefficient determination.

Source: Elaborated by the authors (2016).

Figure 5. Percent residuals in DBH function (cm) for the hypsometric models 2 and 10 obtained from the trees height prediction for Cerrado fragment in Tocantins.
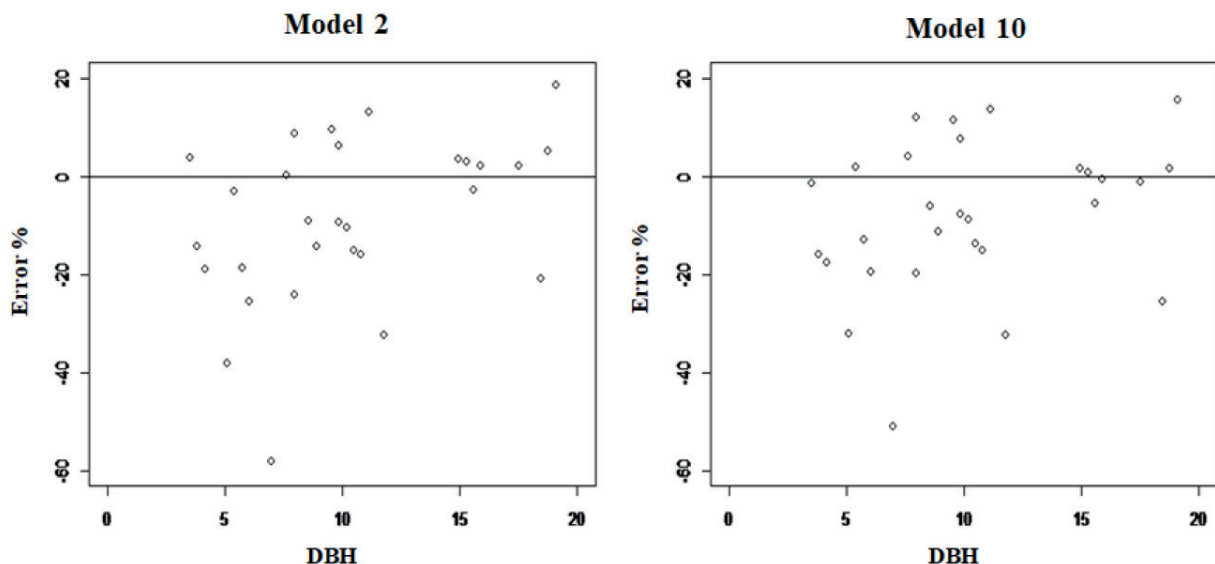
Source: Elaborated by the authors (2016).

Batista et al. (2001), evaluating the stability of hypsometric models, found linear and non-linear models in an area of native tropical forest, estimating the predictive height with R^2 ranging from 0,28 to 0,36 and SRAE from 9.8 % to 80,9 %, with superiority of the non-linear models, concluding

the biological foundation for the models functional form is essential to present appropriate height estimates, a result consistent with the one presented in this paper.

However, it is important to infer, even if the linear models are simpler, non-linear models are recommended due to their ability to explain the trees height and diameter ratio, besides the possibility of biological interpretation of its parameters.

Conclusion

The Statistical adjustment values of the models varied among themselves, R^2aj 0,362 to 0,489 and $s_{H\hat{H}}$:17,58 % to 20,29 %. Regarding the residual analysis, there was a tendency of the models to overestimate the height, reaching up to 40 %.

In general, the non-linear models explained better the dependent variable of height, when compared to the linear models, therefore they are best recommended for estimating heights in Cerrado forest areas.

The best hypsometric model was Prodan (non-linear) for obtaining better statistical values and graphical variation.

Modelos hipsométricos ajustados para um fragmento de cerrado *Sensu stricto* tocantinense

Resumo

Para uma redução dos custos de inventário florestal, os modelos hipsométricos são de grande valia. O presente trabalho teve como objetivo ajustar e avaliar modelos de relação hipsométrica em área de Cerrado em processo regenerativo situada no município de Gurupi (TO). Foram testados dez modelos, incluindo cinco lineares e cinco não lineares, no qual os ajustes foram realizados por meio do software R for Windows. Foram utilizados como critério de seleção do ajuste dos modelos os parâmetros estatísticos do coeficiente de determinação ajustado (R^2aj.), o erro padrão residual ($s_{H\hat{H}}$) e a análise gráfica dos resíduos e, em seguida, a validação dos melhores modelos ajustados. As melhores estatísticas de ajuste foram para os modelos não lineares, com destaque para o modelo de Gompertz (MODELO 7), R^2aj: 0,489 e $s_{H\hat{H}}$: 17,58%. Os modelos, em geral, superestimaram a altura, atingindo até 40 % a mais do que a altura das plantas reais. Diante disso, seis modelos foram para a validação, sendo dois lineares e quatro não lineares. O melhor modelo com a predição foi o Prodan não linear (modelo 10), que obteve melhores valores estatísticos e variação gráfica. Conclui-se que os modelos não lineares explicaram melhor a variável dependente altura.
Palavras-chave: Altura de árvores. Seleção. Validação.

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