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Original Article

Diametric Increment Patterns of Open-Grown and Under Competition *Pinus taeda* L. Trees in Southern Brazil

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Abstract

The main goal of this study was to evaluate the patterns of diametric increment of open-grown and under competition trees of *Pinus taeda* L. as an expression of breast height diameter. The dendrometric variables and the diameter increment of these trees were measured. The increments were obtained by measuring tree rings on cores extracted at breast height using a Pressler borer. An allometric model was fitted to describe the percentage periodic annual increment in diameter (PAId%) as a function of the initial diameter (d_i) for two tree groups. The analysis of covariance (ANCOVA) allowed comparing the effect of intercept (α_0) and slope (α_1) of the fitted equations between groups. The overall average of PAId5 was 0.83 cm year^{-1} for open-grown trees and 0.57 cm year^{-1} for under competition trees. The ANCOVA showed differences in intercept (α_0) – (Pr > F = 0.0066) and not in slope (α_1) – (Pr > F = 0.8883) for the adjusted regression equations. This finding enabled the development of a singular equation to express the increment, using dummy variables, described as: $\widehat{PAId\%} = \exp\left[6.3725 + 0.7982 \times D1 - 1.6212.\ln\left(d_i\right) + \frac{0.1960}{2}\right]$, with R^2 = .69 and Syx = 2.4%. The results of this study contribute to highlight the influences of the growth space in the increment of the species, as well as its maximum potential, elements that are very important for the monitoring and decision-making process in silvicultural activities of individual *P. taeda* trees.

Keywords: Annual tree rings, forest management, individual trees, modeling, potential growth

Introduction

Loblolly Pine (*Pinus taeda* L.), native to the southeastern region of the United States, is an important timber species, and it has been widely planted in tropical and subtropical regions around the world, such as in South Africa, New Zealand, Australia, and Brazil (Albaugh, 2018). In southern Brazil, *Pinus taeda* has been one of the most planted species since the 1960s, due to its adaptability to climatic conditions, its diversity in use, and rapid growth (Bognola et al., 2008). Forests of this genus currently cover an area of approximately 1.43 million hectares in this region, concentrating around 87% of the total pine plantations in the country (Ibá, 2020).

Considering, therefore, the relevance of this forest production, it is essential to understand the growth patterns and factors that affect the trees' increment for researchers and managers to assess and improve silvicultural practices (Lhotka, 2017). In this sense, the estimation and projection of growth in a stand can be carried out by a variety of methods, depending on the required detail, and therefore applicable to the forest, size classes, or trees. In many of the studies developed so far for the genus *Pinus*, and especially for the species *P. taeda*, the growth modeling has been based on size classes models, characterized by the use of a probability density function, as in the studies of Eisfield et al. (2005), Elesbão and Schneider (2011), and Gomes et al. (1997). More recently, although still scarce, initiatives to consider the tree as the basic sampling unit for the species have emerged (Miranda, 2016; Zimmermann et al., 2016), then linked to the concept of tree-level modeling, with expected gains in accuracy in relation to other approaches. For these tree-level models, the accepted hypothesis is that the total growth of the stand is given by the individual sum of each tree that composes it (Hasenauer, 2000; Kuehne et al., 2019).

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In this context, one of the most important factors to simulate the growth of individual trees is the evaluation of the competition effects, that is, the influence of population characteristics where the tree grows. Competition among trees for resources affects the growth rate of woody species, due to limited access to water, light, and nutrients (Johnson & Smith, 2009). This limitation is associated with the growth space, which refers to the availability of all the resources necessary for a tree to exist in a given site, and the extent of this space is influenced by the surrounding trees (Costa et al., 2015).

Conceiving that the degree of competition in a forest determines the individual growth dynamics of trees, then, open-grown trees can be considered as a reference for the maximum potential of a species, in contrast to trees growing under competition (Hasenauer, 1997). Consequently, understanding and comparing the development of open-grown and under competition trees supports the development of management guidelines, helping in the decision-making process associated with interventions in forest stands.

Furthermore, a prerequisite for studies within this perspective is obtaining reliable data. In this space, the analysis of tree rings is an important tool with a potential for rapid response, providing information on the growth rates and age of trees. Studies that use this tool are called dendrochronological, as they investigate changes over time, through the responses expressed by trees (Andreacci et al., 2014).

Modeling of future increment based on a current diameter is practical in comparison to the models that use other independent variables as crown diameter, tree height, age and stand density, indices of competition, among other variables. Therefore, considering the great relevance of the *P. taeda* species for the forestry sector, the present study aimed to evaluate the patterns of diametric increment of open-grown and under competition trees as an expression of breast height diameter (*d*).

Methods

Study Area

The study area is located on the campus of the Federal University of Santa Maria (UFSM), in the Central Depression region of the Rio Grande do Sul state, municipality of Santa Maria, Brazil, between coordinates 29° 43' 10"–29° 43' 21"S and 53° 42' 42"–53° 42' 59"W, approximately 95 m above sea level. According to Köppen's classification, the region's climate is humid subtropical (Cfa), characterized by hot summers and well-distributed precipitation throughout the year, with an average annual precipitation {30 years} of 1720 mm (Alvares et al., 2013). The average annual temperature is 19.1°C, with average temperatures of 32.0°C and 9.0°C during the hot and cold months, respectively (Heldwein et al., 2009). The soil in the region is classified as an Ultisol, and it is present in the sampling area generally in a condition of low natural fertility with a high degree of compaction (Brun et al., 2012).

Two contrasting conditions were evaluated: (i) a dense 50-year-old *P. taeda* plantation with a current density of approximately 550 trees.ha^{-1} (growing in competition), with basal area of ≈68.0 m^2.ha^{-1}, average height of ≈32.5 m; and (ii) a nearby arboretum (<0.3 km) with scattered *P. taeda* trees, under a density of less than 30 trees.ha^{-1} and a grassy understory (open-grown). There were no thinning interventions in any of the stands, the first being characterized by the occurrence of high mortality due to overstocking and the second consisting of solitary trees expressing their empirical maximum tree dimensions, without the influence of competitors throughout their development. Both are located on the same exposure and type of soil.

Data Collection

Ten trees were sampled in each condition type (20 trees in total). The diameter at breast height, considering 1.3 m from ground level (*d*, in cm), was measured with a diametric tape and the height (*h*, in m) with a Vertex IV hypsometer. Additionally, two increment cores per tree were sampled with an increment borer of 0.4 cm in diameter. The samples were air dried and sanded for later analyses of the tree rings and evaluation of diametric increment. The characteristics of the sampled trees are shown in Table 1.

Calculation of Increments

The evaluation of the average rates of periodic annual increment in diameter (PAId) in 5, 10, 15, and 20 years was determined by the expression:

$$\mathrm{PAId} = \left(d_{i+\Delta t} - d_i\right) / \Delta t \quad (1)$$

where PAId is the periodic annual increment in diameter in cm.ano^{-1}, $d_{i+\Delta t}$ is the current diameter in cm, d_i is the initial diameter in cm, and Δt is the annual variation.

The percentage periodic annual increment in diameter (PAId%) was determined to be used in the modeling as a function of the initial diameter (d_i). This type of relationship allows to predict the future increment based on a current diameter, which is calculated by the expression:

$$\mathrm{PAId\%} = \left[\frac{d_{i+\Delta t} - d_i}{d_i}\right] \times 100 \quad (2)$$

where PAId% is the percentage periodic annual increment in diameter, $d_{i+\Delta t}$ is the current diameter in cm, and d_i is the initial diameter in cm.

Model Used to Describe the PAId%

The allometric model (Eq. 3) was linearized (Eq. 4) and used to describe the relationship between PAId% as a function of d_i of open-grown and under competition trees. The model adjustment in the linearized form facilitates the estimation of the regression coefficients, tends to minimize or eliminate heteroscedasticity, in addition to facilitating the analysis of covariance and, subsequently, the development of a single regression model with *Dummy* variables. However, when a nonlinear model is linearized using logarithm properties, it is necessary to correct the logarithmic discrepancy (Baskerville, 1972), estimating with the proper correction in the original scale (Eq. 5):

$$\mathrm{PAId\%} = \beta_0 d_i^{\beta_1} * \varepsilon_i \quad (3)$$

$$\ln\left(\mathrm{PAId\%}\right) = \alpha_0 + \alpha_1 . \ln\left(d_i\right) + \varepsilon_i \quad (4)$$

$$\widehat{\mathrm{PAId\%}} = \exp\left[\hat{\alpha}_0 + \hat{\alpha}_1 . \ln\left(d_i\right) + \frac{\hat{\sigma}_{\mathrm{res.}}}{2}\right] \quad (5)$$

where PAId% is the percentage periodic annual increment in diameter, d_i is the initial diameter in cm; β_0, β_1 = are the regression coefficients in nonlinear form, α_0, α_1 = are the regression coefficients in linearized form, ε_i = is the random error, $\hat{\alpha}_0, \hat{\alpha}_1$ = are the estimation of the equation in linearized form, $\hat{\sigma}_{\mathrm{res.}}$ is the model residual variance in linearized form.

Table 1.
Dendrometric and PAId Characteristics of Open-Grown and Under Competition Trees of Pinus taeda *L.*

Tree	Condition	*n*	*d*	*h*	$PAId_5$		$PAId_{10}$		$PAId_{15}$		$PAId_{20}$	
1	Open-grown trees	25	40.1	20.4	0.82	ABC	0.82	AB	0.91	BC	1.04	BCD
2		24	42.0	17.5	0.77	ABC	0.85	AB	1.13	ABC	1,29	BC
3		20	49.7	15.7	1.17	A	1.10	A	1.40	A	1.73	A
4		25	62.0	18.0	1.00	AB	1.11	A	1.30	AB	1.47	AB
5		38	63.3	20.0	0.48	C	0.39	C	0.45	D	0.51	E
6		36	66.0	21.4	0.61	BC	0.63	BC	0.70	CD	0.74	DE
7		36	69.6	20.0	0.88	ABC	0.81	AB	0.91	BC	0.93	CDE
8		34	73.6	18.6	0.72	ABC	0.73	BC	0.92	BC	0.93	CDE
9		36	78.0	20.8	0.97	AB	0.78	AB	0.97	ABC	1.09	BCD
10		35	98.0	35.0	0.90	ABC	0.95	AB	1.10	ABC	1.24	BC
Overall average		31	64.2	20.7	0.83b		0.82b		0.98a		1.10a	
1	Under competition trees	46	41.1	–	0.51	BCD	0.47	BC	0.56	BC	0.55	BC
2		41	41.5	30.2	0.61	BC	0.56	B	0.56	BC	0.57	BC
3		48	42.9	–	0.54	BCD	0.52	BC	0.45	C	0.45	C
4		46	45.0	32.0	0.69	B	0.57	B	0.52	BC	0.52	BC
5		46	46.8	–	0.31	D	0.33	C	0.38	C	0.47	C
6		46	47.1	–	0.46	BCD	0.48	BC	0.55	BC	0.54	BC
7		47	48.6	–	0.37	CD	0.35	C	0.47	BC	0.50	BC
8		44	52.5	–	0.56	BC	0.51	BC	0.57	BC	0.57	BC
9		47	55.0	33.4	0.58	BC	0.62	B	0.66	B	0.66	B
10		45	69.4	34.5	1.08	A	0.93	A	0.92	A	0.91	A
Overall average		46	49.0	32.5	0.57a		0.53a		0.56a		0.58a	

Note: n = number of tree rings measured at 1.3 m above ground; *d* = diameter at breast height in cm; *h* = total height in m; $PAId_{5,...20}$ = average periodic annual increment in diameter considering 5, 10, 15, and 20 years in cm; – = trees whose heights have not been determined. Means followed by the same letter in the column (uppercase) and row (lowercase) for each group do not differ from each other (α = 5%) by the Tukey's test.

Analysis of Covariance

Analysis of covariance (ANCOVA) was used to verify the existence or not of difference between intercept (α_0) and slope (α_1) of a group of fitted equations (Milliken & Johnson, 2002). In the present study, this analysis compared the adjusted regression equations (Eq. 4) for the group of open-grown trees with those of under competition trees.

Model With *Dummy* Variables Used to Describe the PAId%

The estimation of the PAId% model using *Dummy* variables, with correction for the logarithmic discrepancy, used to distinguish the group of open-grown trees and under competition trees is defined by the following expression (Eq. 6):

$$\widehat{PAId\%} = \exp\left[\hat{\gamma}_{0\left[\text{under competition trees}\right]} + \hat{\gamma}_{0\left[\text{open-grown trees}\right]} \times D1 + \hat{\gamma}_{1\left[\text{under competition trees and open-grown trees}\right]} \cdot \ln\left(d_i\right) + \frac{\hat{\sigma}_{res}}{2}\right] \quad (6)$$

where $\widehat{PAId\%}$ is the estimation of the percentage periodic annual increment in diameter, d_i is the initial diameter in cm; $\hat{\gamma}_{0\left[\text{under competition trees}\right]}$ is the regression coefficient associated with the intercept for the group of under competition trees, $\hat{\gamma}_{0\left[\text{open-grown trees}\right]}$ is the regression coefficient associated with the level for the group of open-grown trees, $\hat{\gamma}_{1\left[\text{under competition trees and open-grown trees}\right]}$ is the regression coefficient associated with slope for the group of under competition trees and open-grown trees, $\hat{\sigma}_{res.}$ is the model residual variance in linearized form, definition of *Dummy* variables: if D1 = 0, the equation is for under competition trees, and if D1 = 1, the equation is for open-grown trees.

Goodness-of-Fit Statistics

The goodness-of-fit of the generated equations was evaluated using the coefficient of determination (R^2 – Eq. 7), standard error of the estimate (Syx – Eq. 8), and graphical residual analysis (Eq. 9), according to the following expressions:

$$R^2 = \left[1 - \frac{\sum_{i=1}^{n}\left(y_i - \check{y}_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}\right] \quad (7)$$

$$Syx = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \check{y}_i\right)^2}{n-p}} \quad (8)$$

$$Residuals = y_i - \check{y}_i \quad (9)$$

Table 2.
Adjustment and Precision Statistics of the Regression Models to Describe the PAId % of Open-Growth and Under Competition Pinus taeda *L. Trees*

Condition	$\breve{\alpha}_0$	$\breve{\alpha}_1$	*F* value	Pr > *F*	R^2	Syx (%)
Open-grown trees	7.1507	−1.6159	750.5	<0.0001	0.70	3.2
	(<0.0001)	(<0.0001)				
Under competition trees	6.3913	−1.6267	1026.7	<0.0001	0.72	1.9
	(<0.0001)	(<0.0001)				

Note: PAId% = percentage periodic annual increment in diameter.

where y_i is the observed value, $\breve{y}_i$ is the predicted value, $\overline{y}$ is the average of observed value, n is the number of observations, and p is the number of coefficients in the model.

Statistical Analysis

Analyses were performed using the Statistical Analysis System (SAS Institute, 2004). The ANOVA procedure was used to compare the PAId considering 5, 10, 15, and 20 years in the open-growth trees and under competition trees. After applying the ANOVA, when significance was found using the *F* test, the means were compared using the Tukey's test ($\alpha = 5\%$).

The GLM procedure (PROC GLM) was used to perform ANCOVA. This procedure uses the method of least squares to fit general linear models. Meanwhile, the REG procedure (PROC REG), which is a general-purpose procedure for regression, allowed the adjustment of the individual models of PAId% in linearized form and with *Dummy* variables.

Finally, the model with *Dummy* variables was investigated for the collinearity of the coefficients, considering the variance inflation value (VIF) lower than 5 as an indication of the absence of a severe collinearity effect.

Results

Characterization of Sampled Trees

On average, 31 and 46 tree rings of open-grown and under competition trees were measured, respectively (Table 1). The averages of the PAId, per tree, at 5, 10, 15, and 20 years, presented different amplitudes between the groups, with values of 0.39–1.47 cm.year^{-1} in open-grown trees and 0.31–1.08 cm.year^{-1} and in under competition trees.

Analyzing the overall averages of the PAId of open-grown trees, no statistical differences were found between the periods of 5 (0.83b cm.year^{-1}) and 10 years (0.82b cm.year^{-1}). Meanwhile, the increments for the 15 (0.98a cm.ano^{-1}) and 20 years (1.10a cm.ano^{-1}) have statistical difference from the younger periods (Table 1). With increasing age, the diameter growth rate of open-grown trees tends to decrease (≈0.27 cm.year^{-1}—at age 15 years).

For under competition trees, the overall average PAId did not differ statistically among the periods of 5 (0.57a cm.year^{-1}), 10 (0.53a cm.year^{-1}), 15 (0.56a cm.year^{-1}), and 20 (0.58a cm.year^{-1}) years, with a trend of stagnation in the growth rate in diameter (Table 1).

Adjusted Equations to Describe the PAId%

The equations adjusted for the group of open-grown trees and under competition trees showed coefficients of intercept ($\breve{\alpha}_0$) and slope ($\breve{\alpha}_1$) significant (Pr > |*t*| = <0.0001) (Table 2). Competition trees have increments with less variation (Figure 1a) and equation with greater fit ($R^2 = 0.72$) and precision (Syx = 1.9%) when compared to open-grown trees statistics ($R^2 = 0.70$; Syx = 3.2%). The residual variance $\left(\breve{\sigma}_{res.}\right)$ used to the correction of the logarithmic discrepancy was 0.2355 for open-grown trees and 0.1698 for under competition trees.

The equations fitted for each group with the correction of the logarithmic discrepancy are expressed by:

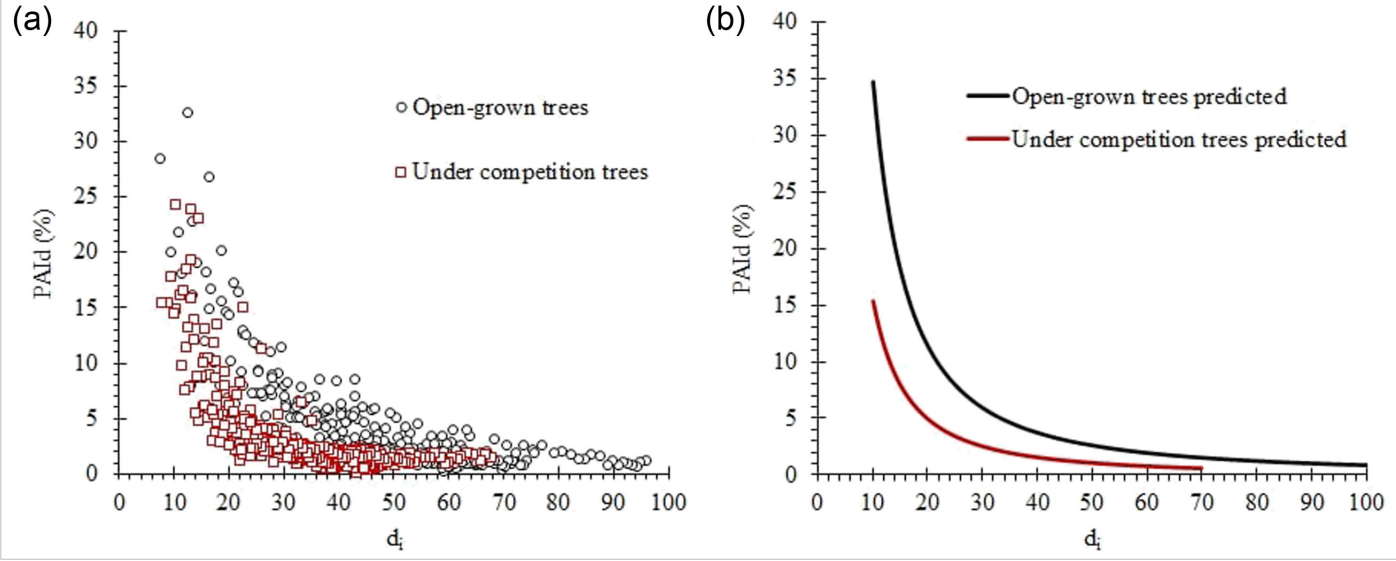

Figure 1.
Pattern of PAId% of Open-Grown and Under Competition Trees of Pinus taeda *L: (a) Observed Data and (b) Trend of Predicted Equations.*

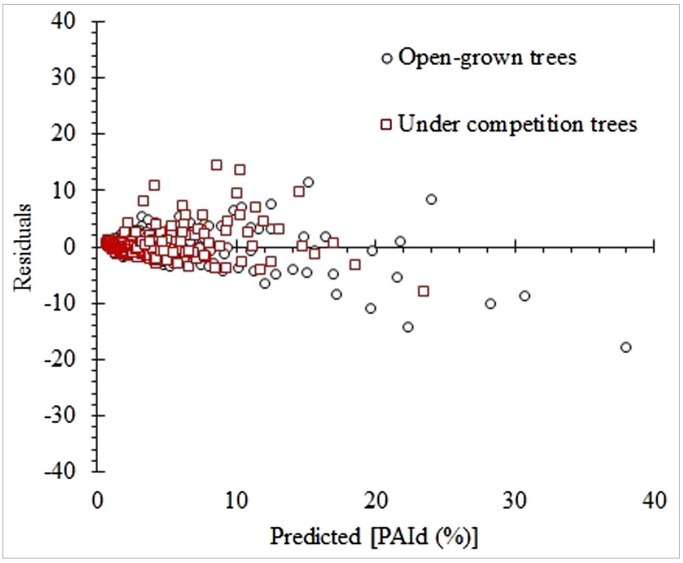

Figure 2.
Residual Graphical Analysis for the Model Evaluated for the PAId% Estimation.

$$\text{Open-grown trees}: \widehat{\text{PAId\%}} = \exp\left[7.1507 - 1.6159.\ln\left(d_i\right) + \frac{0.2355}{2}\right]$$

$$\text{Under competition trees}: \widehat{\text{PAId\%}} = \exp\left[6.3913 - 1.6267.\ln\left(d_i\right) + \frac{0.1698}{2}\right].$$

The trend of observed data and estimated equations of PAId% for both groups presented in Figure 1a and b, showed a difference of ≈20% between the estimated values of PAId% at a d_i equal to 10 cm and still have 0.85% difference at a d_i of 70 cm. Additionally, the residual graphical analysis (Figure 2) shows a good residual dispersion, with low error amplitude and maintaining a proportionality between the under and overestimates, especially for the estimates under competition trees.

Analysis of Covariance

Significant differences were found in the intercept of the equations (α_0) – (Pr > *F* = 0.0066) between the groups of open-grown and under competition trees (Table 3). The same was not true for the slope (α_1) – (Pr > *F* = 0.8883). Therefore, a single regression equation, with the same slope, can be used for both groups.

Equation With *Dummy* Variable Fitted to Describe the PAId%

The equation fitted with the *Dummy* variable showed all the estimated coefficients to be significant (Pr > |*t*| = <0.0001) (Table 4). The statistics calculated for the original scale of the equation showed adjustment (R^2 = 0.69) and precision (Syx = 2.4%) with no severe collinearity of its coefficients (VIF < 5).

The fitted equation with *Dummy* variables allows estimating the $\widehat{\text{PAId\%}}$ for both tree groups simultaneously, and with the necessary correction of the logarithmic discrepancy, expressed by:

$$\widehat{\text{PAId\%}} = \exp\left[6.3725 + 0.7982 \times \text{D1} - 1.6212.\ln\left(d_i\right) + \frac{0.1960}{2}\right].$$

Table 3.
ANCOVA to Evaluate the Effect on Intercept (α_0) and Slope (α_1) of the Fitted Equations to Describe the PAId% of Open-grown and Under Competition Trees of Pinus taeda *L*

Variable	Condition	Intercept (α_0) – Pr > *F*	Slope (α_1) – Pr > *F*
ln(PAId%)	Open-grown trees versus under competition trees	0.0066	0.8883^{ns}

Note: ANCOVA = analysis of covariance; PAId% = percentage periodic annual increment in diameter; ns = not significant.

Table 4.
ANOVA and Adjustment and Precision Statistics of the Equation With Dummy *Variables to Describe the* $\widehat{\text{PAId\%}}$ *of Open-Grown and Under Competition Trees of* Pinus taeda *L*

SV	DF	SS	MS	*F* value	Pr > *F*
Model	2	366.96	183.48	935.9	<0.0001
Residual	762	149.39	0.1960		
Total	764	516.35			
Coefficients	Estimated	Pr > |*t*|			
$\hat{\gamma}_{0\left[\text{under competition trees}\right]}$	6.3725	<0.0001			
$\hat{\gamma}_{0\left[\text{open-grown trees}\right]} \times D1$	0.7982	<0.0001			
$\hat{\gamma}_{1\left[\text{under competition trees and open-grown trees}\right]}.\ln\left(d_t\right)$	−1.6212	<0.0001			
R^2 = 0.69					
Syx = 2.4%					

Note: ANOVA = analysis of variance; PAId% = percentage periodic annual increment in diameter. SV = sources of variance; DF = degrees of freedom; SS = sum of squares; MS = mean square.

Discussion

Competition between trees is one of the strongest determinants of tree size and stem increment. In this sense, open-grown trees represent the empirical maximum tree dimensions, providing indications on the space "*expected*" for a given species to grow without interference from other trees, that is, without harming its growth. Applications of studying trees in this type of condition extend from the development of management guidelines (such as thinning planning) to competition modeling and crown closure (Cavalli & Finger, 2017; Costa et al., 2018; Grote et al., 2020; Hasenauer, 1997; Li et al., 2008; Salih et al., 2019). Furthermore, in the context of growth modeling, open-grown trees are used to describe potential growth, allowing to examine the behavior of trees without competition and then compare changes in vigor due to competition (Weiskittel et al., 2011).

P. taeda is a fast-growing conifer species that presents different characteristics in response to competition. Differences of up to ≈20% were observed in the present study for the species when comparing the increments of open-grown and under competition trees. This growth rate response is clearly associated with differences in the external morphology of the trees, reflecting on the conformations of the growth rings (Tomazello Filho et al., 2017). In general, open-grown trees have larger diameters and less investment in height, while under competition trees generally express smaller diametric dimensions and greater heights, in order to overcome the competition imposed by surrounding trees and achieve greater light availability, as characterized in Table 1. In addition, the larger crown dimensions expected for open-grown trees also have a substantial influence on these reported growth differences, reflecting the greater availability of resources.

Investigating the growth of trees by using the allometric approach avoids time-consuming experiments, and it also delivers valuable information when long time-series on individual tree growth is not available (Hein & Spiecker, 2008). In the present study, we found a strongly significant relationship ($R^2 \geq 0.70$) for PAI% model as a function of the initial diameter (d_i) in both conditions studied, highlighting the possibility of an accurate prediction of the increment based on the initial diametric dimension of the tree**.** Slightly higher estimates for the PAId% equations were observed for the condition of under competition trees (Table 2 and Figure 1), probably as a consequence of the greater homogeneity observed in this condition (less variation in data), characteristic of planting trees with the same age, uniform canopy and little variation in diameter and height. However, the high goodness-of-fit also observed for open-grown trees in conditions of greater heterogeneity reinforces the ability of the generated models.

The significant difference in intercept found in the ANCOVA between open-grown and under competition trees groups especially encompasses differences in PAId% at d_i close to 10 cm. This represents that the density and greater space for growth interfere with the initial growth of trees. In this sense, planting spacing is a crucial decision to avoid early competition (Akers et al., 2013; Aspinwall et al., 2011). This also corroborates with the findings of Dobner et al. (2019), who in a study comparing different levels of crown thinning in *P. taeda* stands, observed significant differences in tree rings width from 6 years of age onward between trees with and without thinning, in a clear association with the available growing space.

Covariance analysis allows us to assess the need or not to use different equations for sites, areas, diameter classes, ages, among others. The identification of non-significant differences between the slopes of the adjusted equations demonstrates that, over time, open-grown trees tend to reduce growth in the same way as under competition trees, changing only the level of the equations. In this sense, management planning and interventions in forests are important to control competition and accelerate growth, in the search for avoiding losses, which can gain even greater relevance in a context of the increasing demand for pine wood for solid end-uses, requiring large stems from longer rotations (Topanotti et al., 2021). Competition, from this angle, can be anticipated, postponed, or eliminated in intensely managed rotations (Ferreira et al., 2020). In addition, this identification of common slope between curves and differences only in level also makes it easy to change the intercept of the equations to different other levels of competition, for example, intermediate to those studied in the present study, thus contributing to species growth estimates and aiding forest management activities.

The use of *Dummy* variables allowed dividing the PAId% estimates into the two groups of trees (open-grown and under competition), with a tendency to decrease the increment rates as the d_i increases. This characteristic reveals a mature phase of the trees, where the juvenile phase of accelerated growth was not observed in this study, as it probably occurred before 10 cm in diameter (Weiskittel et al., 2011).

The relationship modeled in this study provided predicting the future increment of the species based on the current diameter, with a view to practical application, and clearly showed the influence of the growth space, without considering, however, other variables, such as crown diameter, tree height, age, and site (Schröder et al., 2002; Zimmermann et al., 2016). These additional variables should be the focus of further studies in order to reinforce these findings and contribute to refining the assessments and predictions of the species, associated with the planning of forest management actions.

Conclusion

Growth differences of up to ≈20% were observed in the present study for the species when comparing open-grown and competing trees.

The groups of open-grown and under competition trees differ from each other only in intercept for the fitted equations, and a single regression model with a *Dummy* variable is proposed to describe the variation of the percentage periodic annual increment (PAId%) as a function of the diameter.

The results of this study were important for the clear characterization of the influence of the growth space on the species increment, as well as for the investigation of its maximum potential. In addition, further studies will help to reinforce these findings, especially through the inclusion of additional variables, which may contribute to refining the predictions, therefore contributing to the monitoring and execution of silvicultural activities of individual *P. taeda* trees.

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