

Effect of spacing on volume, form factor and taper for *Pinus taeda* trees in Paraná, Brazil

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ABSTRACT: Several forestry procedures affect tree volume and shape, such as spacing, pruning, and thinning. Studying and understanding the effect of these operations on stand attributes are very important for forest management. This study aimed to evaluate volume, form factor, and taper for *Pinus taeda* trees stratified into diameter classes within two planting spacings. In addition, we aimed to evaluate the time spent to scale each tree, measured with a chronometer. Indirect scaling was performed using a Criterion RD 1000. Thirty trees were scaled on each planting spacing (3 m x 2 m and 4 m x 2 m), totaling 60 trees encompassing all diameter classes. Tree volume was calculated using the Smalian equation. Tree volume, form factor, and taper were calculated to each tree and evaluated by stand (independent t-test) and diameter class (variance analysis and Tukey test). The average scaling time was 4 minutes and 35 seconds, which decreased with practice (-24%). Form factor and taper differed with spacing and diameter class. Volume did not differ with spacing, but it did in the diameter classes. We concluded that indirect scaling is a practical method for tree volume assessment; higher planting density leads to more cylindrical stems with lower taper ratios in comparison with denser stands; and the fact that tree volume, form factor and taper differed among the diameter classes should be incorporated into studies of taper modeling.

Efeito do espaçamento no volume, fator de forma e afilamento para árvores de *Pinus taeda* no Paraná, Brasil

RESUMO: Práticas de manejo, como espaçamento, desrama, desbaste afetam o volume e forma das árvores. Estudar o efeito de tais práticas em atributos da floresta é importante para o planejamento florestal. O estudo objetivou avaliar volume, forma e afilamento de árvores de *Pinus taeda* dispostas em dois espaçamentos de plantio e em diferentes classes diamétricas. Além disso, objetivou avaliar o tempo de operação da cubagem indireta, realizada com o Criterion RD 1000. Foram cubadas 30 árvores no espaçamento 3 m x 2 m e 30 árvores no espaçamento 4 m x 2 m, abrangendo todas as classes diamétricas. O volume das árvores foi obtido pelo método de Smalian. As variáveis de volume, fator de forma e taxa de afilamento foram obtidas em nível de árvore e avaliadas por talhão (teste t independente) e por classe diamétrica (análise de variância e Tukey). O tempo de operação médio do dendrômetro foi 4 minutos e 35 segundos, que diminuiu com a prática (-24%). O fator de forma e a taxa de afilamento diferiram entre os dois espaçamentos e entre algumas classes de diâmetro. O volume não diferiu entre espaçamentos, mas diferiu entre algumas classes de diâmetro. Concluiu-se que a cubagem indireta pode ser desempenhada com agilidade na coleta de dados; que maior densidade de plantio gera fustes mais cilíndricos e com menor taxa de afilamento em comparação a povoamentos com menor densidade de plantio e; que as diferenças encontradas entre as classes diamétricas para os atributos das árvores devem ser consideradas em estudos de modelos de regressão de afilamento.

Introduction

The genus *Pinus* is the second most planted in Brazil. Most of the plantations, 87%, are located in Southern Brazil, in Parana (44%), Santa Catarina (26%) and Rio Grande do Sul (17%) states (IBA, 2020). According to IBA (2019), the main use of pine wood is timber, cellulose and paper, panels, and energy, being one of the main species used in the country to produce long fiber cellulose (Shimizu *et al.* 2018).

The requirements of the diverse sectors using pine wood as the raw material are different; therefore, there are different management practices applied to the stands to maximize yield and economic gains in each case (David *et al.* 2018). One of the most important management factors is planting spacing since it affects tree shape, volume, growth rate, and even the frequency of weeding and fertilization. Low-density spacing tends to produce fewer larger trees, which is suitable for the sawmill industry. On the other hand, high-density spacing tends to produce many smaller trees, which are suitable for the pulp and paper industry (Lima *et al.* 2013).

The larger the growing spacing, more available resources for the plant, the faster this growth is, and the stem tends to be more conical and less cylindrical (Silveira *et al.* 2014). Studies have evaluated tree shape and volume under different spacing for *Tectona grandis* L. f (Vendruscolo *et al.* 2016) and *Eucalyptus benthamii* (Watzlawick and Benin, 2020). There is also a study assessing volume for *Pinus taeda* trees planted in different spacing (Lima *et al.* 2013), but they did not evaluate the planting spacing tested in this present study, neither form factor, nor taper in the diameter classes as we did. Taper is another important variable to be considered in the management practices since it depicts tree shape in a value, which is very convenient for the veneer industries for example.

Information allowing tree shape assessment is acquired from scaling, which consists of measuring diameters over a tree stem at several heights. It can be done by measuring tree diameters directly after harvesting, or indirectly, with an optical dendrometer (Campos and Leite, 2013) on standing trees. Indirect scaling is cheaper than direct scaling and can be done by using a Wheeler's pentaprism, a Bitterlich relascope, a Barr dendrometer, or a Criterion, for example (Nicoletti *et al.* 2012). Studies assessed indirect scaling using Criterion RD 1000 compared with direct measurements and observed that indirect scaling is reliable and introduces no tendency to the results (Curto *et al.* 2019; Nicoletti *et al.* 2015b; Oliveira *et al.* 2018). For example, Nicoletti *et al.* (2015a) compared indirect measurements from the optical dendrometer Criterion 400 and RC3H with direct measurements from destructive scaling and found

that indirect scaling was reliable, and that Criterion 400 was the most dependable instrument.

This study aimed to evaluate the volume, form factor, and taper of *Pinus taeda* trees planted in two spacings - and within diameter classes. Besides, we evaluated the time spent to indirectly scale each tree using an electronic dendrometer.

Material and methods

Study area

The study area was composed of two non-thinned *Pinus taeda* stands established in Irati city, Paraná state (25°27'56''S, 50°37'51 W), Brazil. The stands were planted in 2003 by the Forest Department and Forest Management laboratory of Universidade Estadual do Centro-Oeste (Unicentro). The forest was composed of 5 stands which areas varied from 0.76 to 1.65 hectares. Two stands were used in this study. Stand 1 was 1.12 ha and planting spacing was 4 m x 2 m and stand 2 was 0.76 ha and planting spacing was 3 m x 2 m.

The area is steep, located at the Second Plateau of Parana. According to Köppen- Geiger climatic classification, the area is Cfb, in which "c" means hot and temperate climate, with minimal temperature ranging from -3°C to 18°C, respectively; "f" means the absence of dry season; and "b" means mild summers (Alvares *et al.* 2013; Beck *et al.* 2018). Thus, the stands are in a temperate climate with mild summer, subtropical wet season, uniform precipitation and an average temperature of 22°C, and average annual precipitation of 1605,7 mm with frequent frosts (IBGE, 2021; SIMEPAR, 2021). The native cover in the area is a Mixed Ombrophilous Montane Forest also known as Araucaria forest (Roik *et al.*, 2019).

Data

Thirty trees were indirectly scaled in each stand, with the optical dendrometer Criterion RD 1000, totaling 60 trees, in June 2020, when they were 17 years old (Table 1). Trees from all diameter classes were scaled. The 4 cm -diameter classes were empirically established based on the diameter range on the forest, according to the forest inventory conducted in 2019 (Figure 1). In this forest inventory, 11 circle 300 m²-plots were measured. All trees in the plot were measured regarding diameter and 6 trees were measured regarding total height. Before collecting data, the user received a 2-day training, practicing on trees from all diameter classes inside the experimental area. At this training phase, to calibrate the Criterion RD 1000 and to reduce measuring errors, diameters up to 2 meters (0,2 m; 0,5 m; 0,7 m; 1,0 m; 1,3 m; 2 m) were measured directly on the standing tree using a caliper and indirectly using the Criterion RD 1000. From 2 meters and up, the diameters were measured every

Table 1 – Number of trees scaled in each diameter class in the two *Pinus taeda L.* stands assessed in Irati, PR, Brazil.

Diameter class	Diameter class center value (cm)	Number of trees scaled	
		Stand 1 (4 m x 2 m)	Stand 2 (3 m x 2 m)
1	15	5	6
2	19	5	6
3	23	5	6
4	27	5	6
5	31	5	6
6	35	5	-
Total	-	30	30

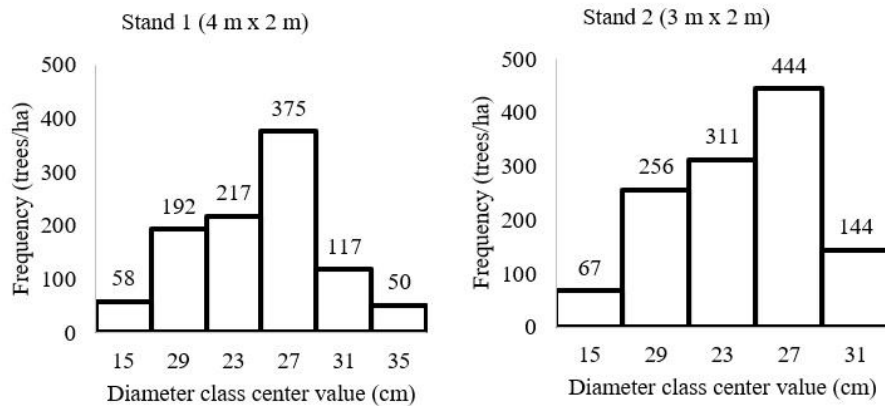


Figure 1 – Frequency (trees/ha) observed in each diameter class for the stands 1 (4 m x 2 m) and 2 (3 m x 2 m) according to the forest inventory performed in 2019, in Irati, PR, Brazil.

one meter, indirectly only, using the Criterion RD 1000. The time spent to scale each tree was measured with a chronometer and recorded. Time was recorded at training and data collection phases for both stands including trees from all diameter classes.

Tree attributes

Tree volume, form factor, and taper ratio were calculated for all trees and compared in the different diameter classes and planting spacings. Processing was done through Excel® and R (R Core Team, 2021). Tree volume was calculated with the Smalian equation using the package *forestmangr* (Braga et al. 2021). The Smalian equation consists of multiplying the average of the upper and lower diameters by the section length. After calculating the volume of each section, they were all summed to obtain the total tree volume. Form factor (ff) (1) was calculated by dividing tree volume by the volume of a cylinder with the same tree height and diameter at DBH as the respective tree (2).

$$ff_i = \frac{v_i}{cv_i} \tag{1}$$

$$cv_i = \frac{\pi * DBH_i^2}{40000} * H_i \tag{2}$$

Where: ff_i is the form factor of the i -th tree; v_i is the volume (m^3) of the i -th tree; cv_i is the cylindrical

volume (m^3) of the i -th tree (m^3); DBH_i is the diameter (cm) at 1.3 m height of the i -th tree; H_i is the total height of the i -th tree.

Taper ratio (3) consists of dividing the difference between two diameters (DBH_i and d_{6i}) by the subtraction of their heights (1.3 m and 6 m), as in Oliveira (2017). Thus, the taper ratio describes the decrease in diameter occurring every meter in tree height. The greatest the taper, the more conic the tree is.

$$tr_i = \frac{DBH_i - d_{6i}}{6 - 1,3} \tag{3}$$

Where tr_i is the taper ratio (cm/m) of the i -th tree; d_{6i} is the diameter at 6 m of the i -th tree; DBH_i is the diameter (cm) at 1.3 m of the i -th tree.

Table 2 summarizes information from the trees scaled at stand 1 and 2, including all diameter classes sampled, regarding diameter at breast height (DBH), height (H), volume (v), form factor (ff), and taper ratio (tr) for stands 1 and 2.

Statistical analysis

Two approaches were taken for statistical analysis. The first approach was to evaluate volume, form factor, and taper ratio on the different spacings. For this, a t-test with 5% of significance was applied to evaluate if there were differences in mean values of volume, form factor and taper ratio between the different spacings. For this test, data from the 5 coincident diameter classes in the two stands (1 to 5,

Table 1) was used, which means 25 trees on stand 1 and 30 trees on stand 2. The t-test is a reliable manner to attest if two values differed statistically.

The second approach aimed to evaluate tree volume, form factor, and taper ratio on the different diameter classes within the planting spacings. The analysis was done by fitting linear models in a completely randomized unbalanced design. Each treatment corresponded to a diameter class within the stand, totaling 11 treatments: 6 treatments with 5 repetitions on stand 1 and 5 treatments with 6 repetitions on stand 2.

The linear model (4) was fit considering tree volume, form factor, and taper as the dependable variables. All assumptions to fit linear models were verified. An analysis of variance and a Tukey test

were performed with 5% of significance on the R software using the packages *agricolae* (Mendiburu, 2020), *emmeans* (Lenth, 2021), *multcomp* (Hothorn et al. 2008), and *car* (Fox and Weisberg, 2019). The package *ggplot2* (Wickham, 2016) was used to produce the figures.

$$Y_{jk} = \mu + T_j + \varepsilon_{jk} \quad (4)$$

Where Y_{jk} is the response variable (tree volume, form factor, and taper ratio) under treatment j and repetition k ; μ is the general average; T_j is the effect of the treatment j ; ε_{jk} is the random error of the model.

Table 2 – Descriptive statistics from the two *Pinus taeda* L. stands, in Irati, PR, Brazil.

Variable	Stand 1 (4 m x 2 m)				Stand 2 (3 m x 2 m)			
	Min.	Max.	Avg.	SD	Min.	Max.	Avg.	SD
DBH_i (cm)	13.0	35.4	24.9	6.6	13.0	32.4	22.9	5.7
H_i (m)	15.1	24.5	21.3	2.3	18.0	24.4	21.2	1.5
v_i (m ³)	0.1322	1.1508	0.5584	0.3129	0.1223	1.0367	0.4905	0.2613
ff_i	0.40	0.54	0.48	0.03	0.46	0.56	0.51	0.03
tr_i (cm)	0.38	1.43	0.88	0.23	0.34	1.43	0.70	0.20

Min.: minimum; Max.: maximum; Avg.: average; SD: standard deviation; DBH_i is the diameter (cm) at 1.3 m height of the i -th tree; H_i is the total height of the i -th tree; v_i means volume of the i -th tree; ff_i means form factor of the i -th tree; tr_i means taper ratio of the i -th tree.

Results

Time to scale the tree using Criterion RD 1000

Scaling time per tree at training was 5 minutes and 24 seconds, ranging from 3 minutes and 13 seconds to 9 minutes and 15 seconds. At data collection, the average time was 4 minutes and 35 seconds, ranging from 2 minutes and 57 seconds to 5 minutes to 31 seconds. This outcome highlights the importance of practicing and training for more efficient tree scaling.

Regarding the stands, more time was spent to scale trees at stand 1 (4 m x 2 m) (4 minutes and 6 seconds) than at stand 2 (3 m x 2m) (3 minutes and 45 seconds) (Figure 2). It is worth mentioning that stand 2 was scaled after stand 1. Therefore, it is unclear if this efficient scaling at stand 1 was due to spacing, practice, or both. Due to this confounding factor, no test was applied to evaluate the scaling time. It is worth mentioning that stands 1 and 2 have very similar total heights (Table 2). Therefore, it is very unlikely that different tree heights on the stands interfered with the scaling time.

Planting spacing

Table 3 shows the average volume, form factor, and taper ratio on the stands 1 and 2, t calculated, and t tabulated. The column “Result” states if tree volume, form factor, or taper ratio differed between the stands. ($\alpha = 5\%$).

The average tree volume did not differ with spacing, but the form factor and taper did. The

closest to 1 the form factor is, the less conic the tree is. The form factor on the greatest spacing (4 m x 2 m) was lower, which implies that trees planted under less dense spacings show a conical shape. For taper, the interpretation is the opposite, the greater the value, the greater the taper, so, more conic the tree, which is more pronounced in stand 1 (4 m x 2 m).

Diameter class within the spacing

Table 4 shows the analysis of variance for tree volume, form factor and taper ratio for the sources of variation “treatment”, “error”, and “total”. F calculated (F -ratio) was higher than the tabulated F , which shows that at least one of the 11 treatments differed, for volume, form factor, and taper.

Figure 3 shows the Tukey test assessing volume, form factor, and taper ratio among diameter classes and spacings. The greater the diameter class, the greater the tree volume, for both stands, except for classes 1 and 2, in which volume did not differ within stands and between the stands. In addition, tree volume did not differ between spacings for classes 3, 4, and 5. Class 6 at stand 1 contains the trees with the greatest diameter and also the greatest volume, statistically different from the trees in the other classes. The form factor was stratified into less conic (a) and more conic trees (b). On the most crowded stand (stand 2), the form factor of trees from the greatest diameter class (4 and 5) differed from the

less-conic-trees group. However, no clear trend on form factor regarding diameter class, and spacing was accused by the Tukey test. Conversely, the

average taper ratio increased with diameter class to all spacing, which means that smaller trees are less conic than the big ones in the other diameter classes.

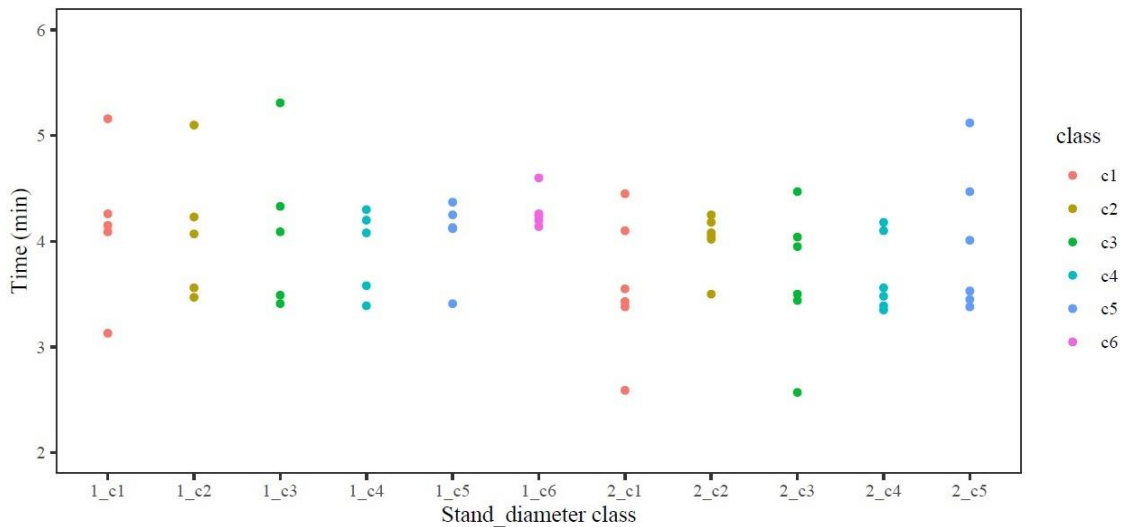


Figure 2 – Time spent for data collection operating Criterion RD 1000 on the different stands and diameter classes in a forest plantation in Irati, PR, Brazil. 1_c1: stand 1 diameter class 1; 1_c2: stand 1 diameter class 2; 1_c3: stand 1 diameter class 3; 1_c4: stand 1 diameter class 4; 1_c5: stand 1 diameter class 5; 1_c6: stand 1 diameter class 6; 2_c1: stand 2 diameter class 1; 2_c2: stand 2 diameter class 2; 2_c3: stand 2 diameter class 3; 2_c4: stand 2 diameter class 4; 2_c5: stand 2 diameter class 5.

Table 3 – T-test with 5% significance comparing tree volume, form factor, and taper ratio for the two *Pinus taeda* L. stands in Irati, PR, Brazil.

Tree attribute	Stand	Average	Calculated t-value	Tabulated t-value ($\alpha=5\%$)	Result
v_i	1 (4 m x 2 m)	0.4646	0.37	2.01	Statistically the same.
	2 (3 m x 2 m)	0.4905			
ff_i	1 (4 m x 2 m)	0.48	-3.74	2.01	Higher at stand 2
	2 (3 m x 2 m)	0.51			
tr_i	1 (4 m x 2 m)	0.86	2.61	2.01	Higher at stand 1
	2 (3 m x 2 m)	0.70			

v_i means volume of the i-th tree; ff_i means the form factor of the i-th tree; tr_i means taper ratio of the i-th tree

Table 4 – Analysis of variance with 5% of significance for tree volume, form factor, and taper ratio considering the diameter class and spacings in a *Pinus taeda* L. forest plantation in Irati, PR, Brazil.

Tree volume					
SV	DF	SS	MS	F-ratio	Sig. ($\alpha = 5 \%$)
Treatment	10	4.5981	0.4598	77.57	2.03
Error	49	0.2905	0.0059		
Total	59	4.8886			
Form factor					
SV	DF	SS	MS	F-ratio	Sig. ($\alpha = 5 \%$)
Treatment	10	0.0301	0.0030	3.33	2.03
Error	49	0.0415	0.0009		
Total	59	0.0716			
Taper ratio					
SV	DF	SS	MS	F-ratio	Sig. ($\alpha = 5 \%$)
Treatment	10	1.5864	0.1586	4.82	2.03
Error	49	1.6106	0.0329		
Total	59	3.197			

SV – Source of variation; DF – Degree of freedom; SS – sum of squares; MS – mean of squares; F-ratio – F calculated; Sig. – F value

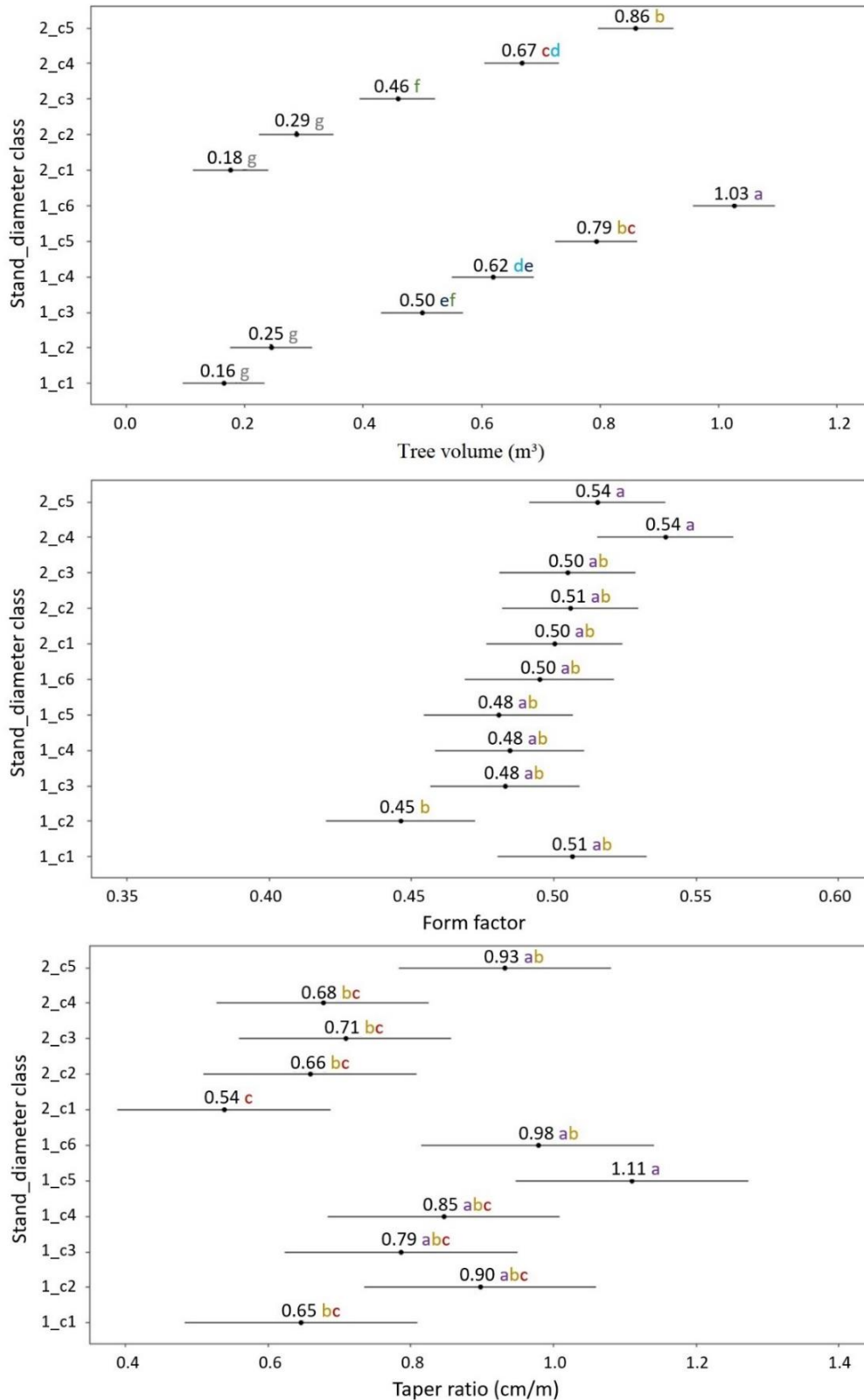


Figure 3 – Tukey test with 5 % significance comparing tree volume, form factor, and taper ratio in the different spacings and diameter classes within spacings for a *Pinus taeda* forest plantation in Irati, PR, Brazil. Treatments with the same letter do not differ statistically. 1_c1: stand 1 diameter class 1; 1_c2: stand 1 diameter class 2; 1_c3: stand 1 diameter class 3; 1_c4: stand 1 diameter class 4; 1_c5: stand 1 diameter class 5; 1_c6: stand 1 diameter class 6; 2_c1: stand 2 diameter class 1; 2_c2: stand 2 diameter class 2; 2_c3: stand 2 diameter class 3; 2_c4: stand 2 diameter class 4; 2_c5: stand 2 diameter class 5.

Discussion

Indirect scaling with Criterion RD 1000

Tree volume was indirectly scaled, which is a method used and validated by authors in many studies (Curto et al. 2019; Nicoletti et al. 2015b; Oliveira et al. 2018). For example, Curto et al. (2019) indirectly scaled 20 *Eucalyptus* spp. trees using Criterion RD 1000. Next, they felled these trees and measured the real tree height using a metric tape, to compare it with the values obtained from indirect scaling using a t-test ($\alpha=0,05$). They concluded that indirect scaling was reliable and unbiased. Similarly, Oliveira et al. (2018) studying 10 *Khaya ivorensis* trees from 5 diameter classes also compared tree height values obtained from Criterion RD 1000 with values obtained using a metric tape. The authors used a test proposed by Borba and Nakano (2016) to attest if the values obtained from Criterion RD 1000 and the metric tape differed and concluded that there was no significant difference between them, with 95% of confidence.

Although there is no study published validating Criterion RD 1000 to indirect scale *Pinus taeda* trees, Nicoletti et al. (2015b) validated scaling using the dendrometer Criterion RD 1000 on 102 trees of native species to an ombrophilous mixed forest. The authors compared indirect with direct scaling and found that diameters obtained from indirect scaling differed 10% on average from the real diameters measured using direct scaling and that volume calculated from indirect and direct scaling differed around 20%.

The many studies attesting reliance for the indirect scaling supports its use, therefore, validating it was not within the scope of this study. However, we controlled the uncertainty by measuring, directly and indirectly, diameters up to 2 meters to compare values and calibrate the dendrometer.

Despite the known reliability of indirect scaling, no study has evaluated the time spent to scale a tree using Criterion RD 1000 before this study. However, Nicoletti et al. (2015b) recognize indirect scaling as a promising non-destructive technique to determine tree volume, biomass, and carbon lowering the costs of forest inventories compared with the direct scaling technique. In forestry, knowing the time spent to accomplish an activity is very important, since the inventories are operations performed in the field, frequently in remote areas, which demand planning regarding fuel, food, and staff. Therefore, being able to more precisely estimate the time necessary to scale the trees certainly helps with planning. Besides, this study showed that time spent to scale a tree decreased with practice, which highlights the importance of training.

Tree volume, form factor and taper

In this study, tree volume differed within diameter classes in the different spacings, similar to results from Lima et al. (2013) and Amateis and Burkhardt (2012), who found spacing affecting tree growth. Lima et al. (2013) compared nine planting spacings (1 m x 1 m, 2 m x 1 m, 2 m x 2 m, 3 m x 2.5 m, 3 m x 3 m, 3 m x 3.5 m, 4 m x 3 m, 4 m x 3.5 m, and 4 m x 4 m) for *Pinus taeda*. They concluded that although volume differed with spacing, it did not differ in very similar spacing according to the Tukey test with 5% of significance. Amateis and Burkhardt (2012) compared tree volume in ten different spacings (4 m x 4 m, 6 m x 4 m, 8 m x 4 m, 12 m x 4 m, 6 m x 6 m, 8 m x 6 m, 12 m x 6 m, 8 m x 8 m, 8 m x 12 m, and 12 m x 12 m) and did not find volume variation at small between-row and within-row fluctuation. In both studies, they did not study the spacing tested in this work (3 m x 2 m and 4 m x 2 m), neither form factor nor taper as we did.

The form factor was also affected by spacing and diameter class, according to the Tukey test. The denser spacing (stand 2, 3 m x 2 m) resulted in trees with a higher form factor (more cylindrical shape) than the trees in the less crowded stand (stand 1, 4 m x 2 m), which resulted in more conic trees. Similarly, Pacheco et al. (2017) compared the average form factor for *Pinus taeda* trees planted in different spacings and observed significantly lower values on trees planted at a lower density. In their study, form factor varied from 0.54 (1 m x 1 m) to 0.46 (4 m x 4 m). In a similar study, Vendruscolo et al. (2016) evaluated form factor for *Tectona grandis* trees planted in four different spacings (3 m x 2 m, 4 m x 2 m, 5 m x 2 m, and 6 m x 2 m) and observed similar form factor on similar planting spacings (3 m x 2 m and 4 m x 2 m). This result shows that the form factor is affected by other stand attributes as well rather than only spacing, such as site index, age, species (Burkhardt and Tomé, 2012).

The larger the spacing, the more space the tree must grow and occupy with its crown (Maestri et al. 2005), producing more leaves to perform photosynthesis and grow (Campoe et al., 2013). Larger crown demands more physical structure at the base to compensate for crown weight and guarantee tree stability, so tree shape tends to be more conical as the crown spreads over. In this study, we observed diameters changing more frequently over the stem at the less-dense spacing, which agrees with the logic of crown growth and stem adaptations to grant a more stable tree architecture. Maestri et al. (2005) also observed higher taper at the larger spacing (1.1 cm/m) than at smaller spacing (0.71 cm/m). As far as we know, no study compared taper in different diameter classes for *Pinus taeda* as we did. Kohler et al. (2016) compared taper stratified into classes of age for *Pinus taeda* trees, which is correlated to

diameter, and found that taper varied with age. In their study, the trees became more cylindrical as the tree aged.

Indeed, the age effect on tree shape is significant. For example, average taper at the diameter classes 5 and 6 on this study were similar to values found by Oliveira (2017) for 14-15-year old *Khaya ivorensis* plantations (around 1.3 cm/m), although they evaluated stand average, not diameter classes averages, as we did. The fact that trees from this study (17-year-old) and trees studied by Oliveira (2017) (14 to 15-year-old) presented similar form factors that can be related to their similar age. Téó et al. (2013) also observed that age affected taper studying *Pinus elliottii* trees in Caçador, SC, Brazil. They found that younger trees have a higher taper ratio than older trees.

Tree volume increased with diameter class, although not significantly to all diameter classes (Figure 3). In these cases, in which volume did not differ between the diameter classes, it is worth to consider grouping diameter classes and perform model identity tests, as in Kohler et al. (2016), and Terra et al. (2018) or to use mixed models setting the diameter classes as random, as in Ferraz Filho et al. (2018), instead of modeling volume and taper within diameter classes (Favalessa et al. 2012). In this sense, Sanquetta et al. (2016), aiming to improve volume modeling for *Araucaria angustifolia* trees, tested three approaches, stratifying their database by form factor, form factor per diameter class, and regression analysis. They concluded that the average form factor per diameter class was the most precise and accurate predictor, which contradicts the common knowledge that modeling volume yields bring better results than using form factor to calculate tree volume. It highlights the need for more studies regarding tree attributes related to volume and shape (form factor and shape) since increasing precision on the estimates helps planning in the industry.

Conclusion

Time spent operating Criterion RD 1000 to scale tree volume dropped 24% with training, which shows the importance of practicing for more efficient measurements. Lower planting density (4 m x 2 m) produced more conical stems with higher taper (diameter decreasing more over the stem) compared to the higher-density stand (3 m x 2 m). *Pinus taeda* tree volume, form factor, and taper ratio significantly differed among the diameter classes, but not in all cases; therefore, we recommend this information to be taken into consideration when fitting taper regression models.

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