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Density of *Araucaria angustifolia* wood from overstocked stand

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Abstract - The aim of this work was to evaluate the radial and longitudinal variations of wood specific gravity in an overstocked stand of *Araucaria angustifolia*, with 65 years. The stand was located in the National Forest of Açungui, Campo Largo, Parana State, Brazil, with thinning recorded between 1970 and 1980, without subsequent thinnings. We selected three trees for each diameter class: 10-30 cm, 30-50 cm and 50-70 cm. To the longitudinal analysis, we collected discs from seven heights (0, 20, 40, 60, 80 and 100% of commercial stem and at 1.3 m). The barks were removed and it was obtained opposite wedges until pith and five samples were taken in radial direction from each disk. In general, there was an increase of wood specific gravity in radial direction. The average differed significantly along the stem, with decreasing trend of wood specific gravity in the longitudinal direction. However, average specific gravity at 60% of commercial height was higher than at 40%, than reducing to the top, indicating effect of competition that occurred in the area. The no uniform wood along stem indicates negative effects of the lack of management in the stand.

Massa específica básica da madeira de *Araucaria angustifolia* em povoamento superestocado

Resumo - O objetivo do presente trabalho foi avaliar as variações radiais e longitudinais de massa específica básica da madeira em um plantio superestocado com 65 anos de *Araucaria angustifolia*. O plantio, localizado na Floresta Nacional de Açungui, Campo Largo, PR, foi desbastado entre 1970 e 1980, não havendo registros de desbastes posteriores a essa data. Foram selecionadas três árvores para cada classe de diâmetro: 10-30 cm, 30-50 cm e 50-70 cm. Para a análise longitudinal, foram seccionados discos em sete alturas (0, 20, 40, 60, 80 e 100% da altura comercial e a 1,3 m do solo), sendo removidas as cascas e retiradas duas cunhas opostas até a medula e cinco corpos de prova no sentido radial de cada disco. Em geral, na direção radial houve aumento da massa específica. As médias da massa específica diferiram estatisticamente ao longo do fuste, com diminuição da massa específica na direção longitudinal. No entanto, a massa específica média a 60% da altura comercial foi maior do que a 40%, com redução a partir dessa altura em direção ao topo, indicando efeito da competição que ocorreu na área. A desuniformidade da madeira ao longo do fuste é um indicativo dos efeitos negativos da falta de manejo na área.

Introduction

There are many factors influencing the suitability of wood to the most various uses. However, many researchers consider the wood density as the most important wood quality attribute, since it is related to many features, including strength, stiffness and dimensional stability (Panshin & De Zeeuw, 1970; Burger & Richter 1991; Latorraca & Albuquerque, 2000; Silva et al., 2004; Jyske et al, 2008). Furthermore, the determination of wood density is a simple and practical way of expressing the quality of the wood.

Hereditary tendencies, physiological and mechanical influences as well as environmental factors and silvicultural treatments affect the structure of the wood and thus its density (Kollmann & Côté Junior, 1968; Panshin & De Zeeuw, 1970). As the stand close and natural competition starts, the lower branches begin to die and a progressively stem more free of branches is produced. As a result, the living crown moves away from the base, which results in the decrease of wood production as well as changes in the distribution of growth along the stem and late wood contents in the growth rings, being a determining factor in the type of wood formed in the stem (Larson, 1963).

Thus the impact that thinning exerts on the development of the crown and on growth rate may have a significant effect on the wood formation (Malan, 1995). Therefore, the reduction in the initial growth rate by means of controlling the initial density of the population and thinning programming may result in a lower proportion of juvenile wood in favor of a further increase in the wood density (Hans et al., 1972).

The wood density variations may be radial (from pith to bark) and / or axial (from the base to the top), and are affected by the width of the annual rings or the percentage of juvenile wood (Kollmann & Côté Junior, 1968) and intra-ring variation (Panshin & De Zeeuw, 1970). With respect to changes of wood density for conifers, there is, in general, an increase from pith to bark and a decrease with the increase in height of the stem (Elliott, 1970). The degree of wood density variation may serve as a parameter for separating the timber into quality classes according to the part of the tree in which it was removed.

There is good knowledge of how the leaf organs control the formation of wood in the stem. When you know the planting development history, it is possible to explain how the quality of wood was affected by past growth conditions (Larson et al., 2001).

The objective of this research was to evaluate, among trees of different diameter classes, the radial and longitudinal variations of wood density in an overstocked plantation of *Araucaria angustifolia* (Bert.) O. Ktze., in order to verify probable influences of competition that occurred in the past.

Material and methods

Study area and data collection

The study was conducted in a plantation of *A. angustifolia*, established in 1946 in the National Forest (FLONA) of Açungui, located in Campo Largo, Paraná State, occupying an area of approximately 131 ha, with a record of thinning conducted between 1970-1980. During this study the stand presented 65 years old and it was under intense competition.

The trees selected and felled (SISBIO 35355-1) represent the current diameter classes of 10-30 cm (Class 1), 30-50 cm (Class 2) and 50-70 cm (Class 3). The samples were collected from three trees per diameter class.

Samples preparation

For the determination of the radial variation of the wood density at different heights, each tree had discs sectioned into seven different heights: 0.10 m, 20%, 40%, 60%, 80% and 100% of the commercial height, and 1.30 m from the ground (dbh). From each disk the barks were removed and it were taken samples from opposite wedges (A and B) and five in the radial direction, from pith to bark, in accordance with the distance from the pith to the last ring before reaching the bark, as shown in Figure 1.

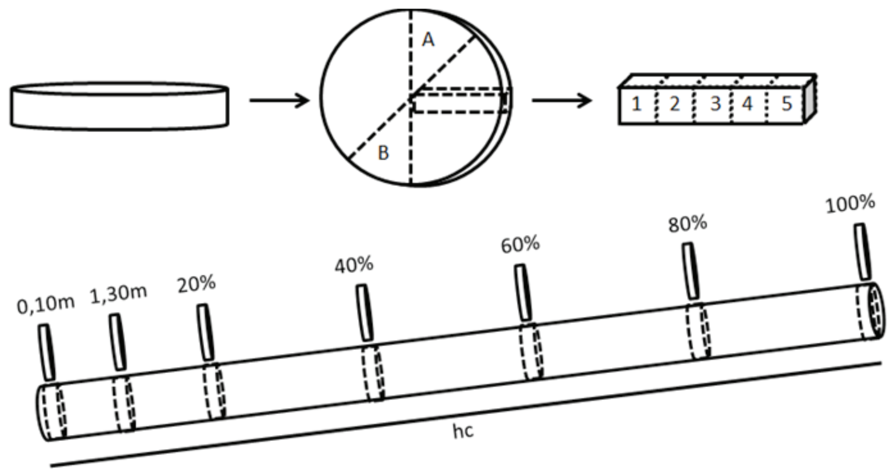

Figure 1.Schematic view of discs and samples collected to determine wood density in axial and radial directions. Hc = commercial height.

Determination of wood density

The samples for wood density determination were previously identified and kept submerged in water. A vacuum pump was used until complete saturation.

The wood density was obtained by the ratio between the dry mass and the saturated volume. The dried mass was determined by keeping the wood samples in an oven at 103 °C ± 2 °C until constant weight. The saturated volume was determined in wood samples submerged in water until constant weight. The determination of wood density was performed according to the NBR 7190 norm (Associação Brasileira de Normas Técnicas, 1997).

Statistical analysis

For data analysis, each tree was considered as a repetition in its diameter size class. Statistical analyzes were based on a completely randomized design with split plots. The effect of the classes in the longitudinal direction in addition to the effect of this direction in the radial direction were evaluated through analysis of variance, by adopting the 95% level of probability; when differences between the effects in question were observed, it was applied Tukey test at 95% of probability.

To evaluate the variation in wood density in the longitudinal direction, the average value of the wedges on each disc was obtained and, for the variation in the radial direction, bodies of the test piece 1 to 5 (pith-bark) of each disk were used.

Results and discussion

The average wood density along the stem presented no statistical differences among the three diameter classes considered. So, the variation in wood density in the longitudinal direction was processed for all classes together, and it was observed statistically different averages, as displayed in Table 1.

Table 1. Average values of wood density in the longitudinal direction of stems of *A. angustifolia*.

Sample	Height	Averages ($g.cm^{-3}$)	Standard deviation ($g.cm^{-3}$)
0	0.10 m	0.5045 a	0.033326
1	1.30 m	0.4844 ab	0.022979
2	20% of the commercial height	0.4594 bc	0.021855
3	40% of the commercial height	0.4344 cd	0.023200
4	60% of the commercial height	0.4501 bc	0.033736
5	80% of the commercial height	0.4046 d	0.029217
6	100% of the commercial height	0.3619 e	0.062852
Average		**0.4427**	

In which: averages followed by the same letter do not differ statistically among themselves according to the Tukey test at 95% of probability.

A similar result was observed by other authors. While planting *A. angustifolia* in 1971, Wehr & Tomazello Filho (2000) found no significant differences among trees from dominated (dbh < 21.50 cm), co-dominant (21.50 ≤ dbh < 31.51 cm) and dominant classes (dbh ≥ 31.52 cm), and observed wood densities of 0.50, 0.53, 0.48 g.cm^{-3}, respectively. In 30 years stand of *Pinus taeda* L. in southern Brazil, Dobner Junior (2014) concluded that the wood densities of trees of different diameter classes are relatively homogeneous regardless of the thinning variation. Differences were found only in one class, but these differences were small and presented no evident relationship with the thinning variants.

In a forest assessment conducted in the study area, the variables of the crown diameter (cd) and the diameter at 1.30 m from the ground (dbh) were measured, determining Pearson correlations at 95% of probability among these variables. A significant correlation (0.87) was therefore obtained. As dbh increases, the crown diameter also increases, thereby resulting in a positive correlation (Curto, 2015). Thus, it can be considered that the dimensions of the crowns at the current moment have been shaped by competition, as its sociological position is strongly correlated with the dimensions achieved by the stems.

In a comparison among dominant, co-dominant and suppressed trees within plantations, Panshin & De Zeeuw (1970) reported an increase in wood density with the removal of trees of the same age, when considering the same sample position within the stems. In this study, the dominant trees presented tracheids with larger diameters, shorter lengths and lesser density than suppressed trees. Beltrame et al. (2010) in a *A. angustifolia* plantation established in 1966, found differences in wood density at 12% moisture among the lower strata (average dbh of 9.8 cm), medium (average dbh of 16.2 cm) and higher (average dbh of 26.7 cm), which were respectively 0.4404, 0.4725 and 0.5122 g.cm^{-3}.

Many studies have examined the relationship between the population density at a stand and the timber properties, but few have quantified the relationship between canopy characteristics and timber properties (Amarasekara & Denne., 2002; Lachenbruch et al, 2011; Kuprevicius et al, 2013.). Larson (1963) points out that in a closed population, the percentage of latewood varies according to the class and the development of the canopy. Thus, a dominant tree, with vigorous canopy, produces wide ranges of early wood and consequently lower wood density, since the trees from the lower classes usually have higher percentage of latewood and therefore a denser wood compared to those of the upper strata of the same stand.

The average specific mass obtained (0.4427 g.cm^{-3}) for the evaluated trees is close to that found by other authors that evaluated the same species, even under different conditions and ages. Mattos et al. (2006) obtained wood density of 0.425 g.cm^{-3} when using samples of nine trees with 33.5 cm of dbh in a plantation with 38 years old; Melo et al. (2010), evaluating the wood density of three trees with dbh greater than 40 cm, from a 50 years old plantation in the FLONA of San Francisco de Paula, found an average of 0.435 g.cm^{-3}; Mattos et al. (2011) showed average values of 0.40 g.cm^{-3} for trees with 19 years old, which suffered two interventions of thinning, and found that the density decreased with height in the tree; and Rose et al. (2013), using ten samples with ages ranging between 24-29 years from FLONA Irati, PR, found average wood density of approximately 0.435 g.cm^{-3}.

In general, a decrease in density in the longitudinal direction is observed. However, at 60% of the commercial height, the average density was greater than at 40% of the commercial height (Table 1).

Considering the variation of wood density in longitudinal direction, the results in the literature show some disagreement. Nevertheless, according to Elliott (1970), the decrease in the wood density by increasing the height is the general trend shown for conifers, which could be observed in the works of Palermo et al. (2003) with species of the *Pinus*, in those of Jyske et al. (2008) studying *Picea abies* (L.) Karst. and also in those of Mattos et al. (2011), who studied *A. angustifolia* and two species of *Pinus*.

According to Tsoumis (1991), in conifers the trend to reduce the wood density as tree height increases is attributed to mechanical and biological factors. Under the mechanical point of view, the stem is the support of the tree which under the influence of factors acting in the canopy, tend to support the various forces, resulting in the formation of higher wood density and therefore greater resistance. In additional to mechanical factors, a greater density in the base of the tree is related to the formation of the heartwood, and its contribution to the density differences are more pronounced when the color contrast between the heartwood and sapwood is intense. The darker color of the core is caused by deposition of extractives, which are lighter than the material of the cell wall, but their presence contribute to its higher density because they permeate cell walls or are deposited in cell cavities.

According to Kollmann & Côté Jr. (1968) when the development of conifers is slow, the ring width and the thickness of the transition zone are reduced, and with the increasing competition the percentage of the initial wood decreases, and the proportion of latewood increases, increasing the wood density for slow-growing trees.

According to Larson et al. (2001), with the increase of the trees age and its growth in height, the closest portion to the ground becomes farther away from the most active portions of the crown. Thus, the tracheids of early and late wood become more differentiated and the transition region becomes sharp. The maturation process of the growth rings begins at the stem base and progresses in height with each increment. The wood in the portion next and in the crown continues its formation with similar characteristics to juvenile wood. The concomitant progression in height increase of mature wood and decrease in juvenile wood formation results in a central cylinder of juvenile wood that extends through the stem. Although the juvenile wood formed in the young tree is not identical to the wood formed in the stem next to the crown of old trees, they are sufficiently similar in their characteristics, so that in practice we can consider them identical. Furthermore, according to Tsoumis (1991), the amount of juvenile wood influences the vertical variation, since a large amount in the upper part of the stem causes the density values to be smaller than the base.

In general, it can be noted reduction in wood density along the stem. The more evident variation was observed in the sample taken at 100% of the commercial height (Table 1), where there is a more juvenile wood. Some reports indicate that the wood density is higher at the bottom, with a decrease along the stem and an increase after half of the height towards the top of the tree (Yanchuk et al., 1983; Vale et al. 1999, 2009) or even from lower heights, as observed by Dibdiakova & Vadla (2012). One explanation for the trend of increased wood density is the response of trees to support the weight of the branches (Vale et al., 1999). However, differently than expected, this work noticed the greatest amount at 60% of the commercial height, compared to 40% height, and observed, from 60%, a new trend of reduction of wood density towards the top of the tree. Possibly, reversing the upward trend of the density was a result of increased competition, which causes enlargement of the growth rings in the highest parts, resulting in the formation of more cylindrical stems (Assmann, 1970; Andrade et al., 2007, Curto, 2015).

The lack of uniformity in the wood density along the stem could also be the result of a later thinning, since after this the efficiency of the living crown increases, resulting in an increased production of wood, being susceptible to changes in quality, as stated by Larson (1963). Thus, it is possible to affect the uniformity of the features of the wood in a stand subjected to thinning (Peltola et al., 2002). It is important to highlight that a proper thinning procedure does not aim at enlarging the diameter growth of dominant trees, but rather at avoiding the suppression of its growth (Kramer & Kozlowski, 1960).

Brazier (1970), working with *Picea sitchensis* (Bong.) Carr also noted that the wood density is influenced by the growth rate, having as effect an increase in the initial wood content without a corresponding increase in the late wood. Thus, when a thinning is followed by radial increment higher than in previous years, there is a reduction in the wood density. However, in order to avoid sudden changes in the growth rate of the diameter as might occur when thinning is performed with a delay; it would be better to release it from the competition before it achieves high levels (Smith et al., 1997).

In order to evaluate the density variation in the radial direction, all trees were considered regardless of the current diameter class, since no differences were found between them when evaluated in the longitudinal direction. The wood densities in the radial direction at different heights and in longitudinal direction at different radial positions are displayed in Table 2.

Table 2. Wood densities averages in radial and longitudinal directions for *A. angustifolia* stems.

	Pith								Bark		
Height	Position 1		Position 2		Position 3		Position 4		Position 5		
0	0.4742	a	A0.4923	a	A0.4936	a	A0.5151	a	A0.5144	a	A
1	0.3880	b	C0.4394	ab	B0.4760	a	AB0.5004	ab	A0.5008	ab	A
2	0.3503	b	C0.3968	ab	B0.4534	ab	A0.4885	ab	A0.4825	abc	A
3	0.3389	b	C0.3808	b	BC0.4239	ab	AB0.4513	bc	A0.4547	bc	A
4	0.3927	b	B0.4216	ab	AB0.4479	ab	AB0.4670	abc	A0.4573	bc	AB
5	0.3785	b	A0.4108	ab	A0.4187	ab	A0.4309	cd	A0.4297	c	A
6	0.3450	b	A0.3640	b	A0.3743	b	A0.3822	d	A0.3748	d	A

Where: vertical lower case letters indicate the difference in the longitudinal direction; and horizontal uppercase letters indicate the difference in the radial direction. The averages followed by the same letter do not differ by Tukey test at 95% of probability.

When assessing the effect of height on the variation of wood density in the radial direction, it was observed that the samples in the position 1 (closer to the tree pith) the wood density was higher on the base, and thereafter there was no statistical difference as height increased along the stem, due to the predominant presence of juvenile wood (Table 2).

Once assessing the wood density variation in the radial direction in each considered height (Table 2), in general it was observed an increase in wood density from pith to bark at all heights, except for the heights 5 and 6, which statistically showed the same average wood density in the radial direction, with lower densities compared to the other heights.

Rolim & Ferreira (1974) studied *A. angustifolia* trees of commercial stands with 15 years old and found that the wood density of each growth ring increased in pith-bark direction, presenting a markedly linear increment. The density in that study varied from 0.363 $g.cm^{-3}$ in the ring 2 to 0.522 $g.cm^{-3}$ in the ring 14, showing that commercial planting trees suffer greater variation of density in the early years of life in comparison with trees of natural forests.

The increase in wood density from pith to bark, obtained from slow growth, may result in better quality wood. The reduction in initial growth rates by controlling the initial density of the population in addition to late thinning may result in a lower proportion of juvenile wood in favor of a further increase in density. Thus, the rapid growth achieved in older ages due to silvicultural operations tends to reduce the wood density near the periphery and to produce a timber with little or reduced wood density gradient in the direction from pith to bark (Hans et al., 1972). The trend of wood density increases in radial direction has been addressed by several authors in different broadleaf species (Rezende & Ferraz, 1985; Tomazello Filho, 1985; Cruz et al. 2003; Gonçalves et al., 2009; Teixeira et al., 2011), and conifers (Amaral et al., 1971; Higa et al., 1973; Foelkel et al., 1975; Rao et al., 1995; Nogueira & Vale, 1997; Pereira & Tomaselli, 2004).

While assessing the influence of thinning on the wood quality of *Pinus elliottii* Engelm., Pereira & Tomaselli (2004) observed increase trends in wood density due to the rise in the thinning intensity, in the dbh height. However, the authors explained that the results are due to the radial variation of the wood density according to the tree age, with a trend of increase from pith to bark. In these conditions, we have two factors acting on the wood density: the competition and the age, both directly contributing to the increase of this variable.

The reaction of trees to thinning varies according to the age of the stand, especially as the ratio between the amount of the active part of the crown and the height of the stem decreases with the age of no thinned stands. Trees in stands that remain without thinning, until the crowns get too small, do not often react to thinning, possibly because the release increases more the total respiration than the total photosynthesis. Thus, it is possible that the trees in overstocked stands have insufficient reserves to quickly develop a wider crown, which could be able to carry on some greater production of photosynthesis. Furthermore, it is possible that the canopy of such stands contain large proportion of shade leaves, which may be damaged by a sudden direct sunlight (Kramer & Kozlowski, 1960).

Even though there are several studies concerning the influence of thinning on the wood density of conifers, the results have been contradictory. Peltola et al. (2007) and Guller et al. (2012) found that the thinning increased the average wood density, Barbour et al. (1994) found a reduction, while others found no thinning effect on the wood density (Mörling., 2002; Jaakkola et al, 2005; Jyske et al, 2008;. Vincent et al, 2011.). This contradiction is reason for discussion, since woods of different ages have been compared. The magnitude of such thinning effect on the wood features depend on the intensity and type of thinning, the species, the condition of the tree on a stand and whether a juvenile or an adult timber is formed (Tasissa & Burkhart, 1997).

Once we examine whether the development of the canopy influences the formation of the timber, it becomes clear how changes in the growth conditions can affect this relation. Thus, it can be inferred that the planting conditions and the silviculture practices can significantly influence the quality of wood based on alterations in the crown-stem ratio (Larson et al., 2001), thereby it would be possible the achievement of a more homogeneous wood controlling the competition between trees. So, the management planning aimed at a balanced tree competition with periodic thinning would enable the production of wood with less wood density variation, in order to reduce problems in the mechanical processing, and also to increase the size of the remaining trees.

Conclusions

The competition does not seem to exert influence on wood density among trees of different diametric classes from the same stand.

In general, the density has increased in the radial direction, from pith to bark, and has decreased in the longitudinal direction, from base to crown. This trend has been changed possibly due to a period of intense competition that caused unevenness wood along the stem.

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