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QUALITY OF THE WOOD *Swietenia macrophylla* FROM PLANTING IN THE CENTRAL AMAZON

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Abstract: The aim of this study was to determine the quality of wood from *Swietenia macrophylla* in commercial plantation aged 20 years in the Central Amazon. The planting has a total of 100 hectares, with initial spacing of 7 m x 6 m. Five trees were selected for sampling by destructive method. The quality of the wood was evaluated considering the physical and mechanical properties. A completely randomized design was used considering a probability level of 95%. The only variable that did not show a significant difference between shafts was MOE compression. For the other variables, the stems with the best performances were those with a diameter between 25 cm and 35 cm. The wood from: *Swietenia macrophylla* in planting for 20 years, it has a high modulus of rupture, medium modulus of elasticity, medium shear strength, medium hardness and medium resistance to compression parallel to the fibers, indicating the possibility of use for commercial purposes.
Keywords: Brazilian Mahogany; Physical properties of wood; Mechanical properties of wood.

INTRODUCTION

Timber production in the Amazon moves an important economic chain for income generation in the region. However, the high commercialization of wood can put pressure on the exploitation of the few species of commercial interest listed by the main companies, with growth rates incompatible with the intensity exploited (Reis et al., 2019). Thus, planted forests are an important alternative in the supply of wood for industrial purposes, replacing that derived from natural forests (Benin et al., 2017).

In Brazil, there is a predominance of genders: *Pinus* e *Eucalyptus* in the cultivation of commercial forests against native species. Until a few decades ago there were no planted forests in the Amazon region. However, an increase in the demand for wood has led to the search for new alternatives in the production of native species, which may be advantageous due to their adaptability and local adaptability (Vidaurre et al., 2018).

In this context, Brazilian mahogany, (*Swietenia macrophylla* King) has commercial potential for use in planted forests because it is a species known worldwide and for the characteristics of its wood, such as: good workability, high dimensional stability and attractive aesthetic appearance (Fadillah et al., 2014; Langbour et al., 2011; Lestari et al., 2015). These characteristics direct the use of wood for the manufacture of furniture, moldings, internal finishing panels, decorative veneers, musical instruments, in components of the aviation and naval industry, and handicrafts (Krisnawati et al., 2011; León, 2010), adding value to your processing.

Being able to be compared to wood of native origin in terms of quality parameters, there is still a lack of technological and scientific information regarding the quality of the wood and the management of Brazilian Mahogany (Langbour et al., 2011; Silva et al., 2019). Thus, the aim of this study was to determine the quality of Brazilian Mahogany wood

(*Swietenia macrophylla* King) in a 20-year-old equine plantation located in the Central Amazon.

MATERIAL AND METHODS

STUDY AREA

The study was conducted in a plantation of 100 hectares of Brazilian Mahogany (*Swietenia macrophylla*) located in the city of Itacoatiara, state of Amazonas, Brazil, with access via Highway AM 010, Km 172, with geographic coordinates corresponding to Latitude -02 55' 04.17360' and Longitude -59 07' 27.05160" (Figure 1). Planting took place between April and June 1999 with an initial spacing of 7 x 6 m and a total of 21,957 seedlings. There were no silvicultural treatments on the trees to improve growth. The applied practices were directed towards the harvest of other existing crops intercropped between the mahogany trees such as mechanized cleaning of the accesses for fruit removal.

In the area there is a predominance of dense tropical forest on terra firme with vegetation cover rich in botanical species, where various strata can be observed, formed by herbaceous or woody plants, subshrubs, shrubs and finally arboreal individuals (IBGE, 2012). The local climate is classified, according to the Köppen classification, as Climatic Group A (Tropical Rainy Climate), covering the type and climate variety Amw (monsoon-type rains). The average annual rainfall varies between 1,355 and 2,839 mm, with the highest volume in the months from January to April and the lowest monthly volume between August and October. The average temperature varies between 25.6 °C and 27.6 °C and relative humidity between 84% and 90% on average. The soils are predominantly of the Dystrophic Yellow Latosol type, with low natural fertility and high aluminum content, with pH varying between 4.3 and 4.7, aluminum saturation between 85 and 90% and phosphorus content below 4 $mg.dm^{-3}$.

DATA COLLECTION

Data collection took place in January/2020. Five trees were randomly selected at planting to evaluate wood quality (considering physical and mechanical properties) using a destructive method. The stem was sectioned to remove disks for analysis of physical properties and unfolded using a chainsaw to obtain planks with variable lengths corresponding to each section of the stem to be analyzed for mechanical properties (Figure 2). Sampling was carried out comprising, when possible, the entire dimensional structure of the log.

PHYSICAL PROPERTIES

The physical properties analyzed were moisture content and basic density. For this analysis, five 5 cm thick disks were removed from each tree at the points corresponding to the positions: base, DBH, 50%, 75% and 100% of the commercial height, the latter considered from the base to 6 cm before the place of insertion of the first branch into each trunk. The specimens for the tests were made in accordance with NBR 7191 of the Brazilian Association of Technical Standards (ABNT, 1997), totaling 150 with dimensions of 2.0 cm x 3.0 cm x 5.0 cm.

MECHANICAL PROPERTIES

The analyzed mechanical properties were Fiber Parallel Compression (MOE and TFM), Static Flexion (MOE and MOR), Janka Hardness and Shear. The samples for this analysis were made from planks with variable lengths corresponding to each section of the stem removed using a chainsaw after removing the disks referring to the samples for physical properties. The specimens were prepared according to the standard: *American Society for Testing and Materials* – ASTM D 143-94 (ASTM, 2000), which totaled 139, with varying quantity and dimensions according to the analyzed property (Table 1).

STATISTICAL ANALYSIS

The data were tabulated and through descriptive statistics the following were evaluated: Mean, standard deviation, variance, maximum and minimum. The assumptions of normal distribution of residuals (Shapiro-Wilk test) and homogeneity of variance (Levene test) were analyzed (Zar, 1999). To compare the physical and mechanical properties between the shafts, a completely randomized design was used.

For normally distributed variables with homogeneous variance, a completely

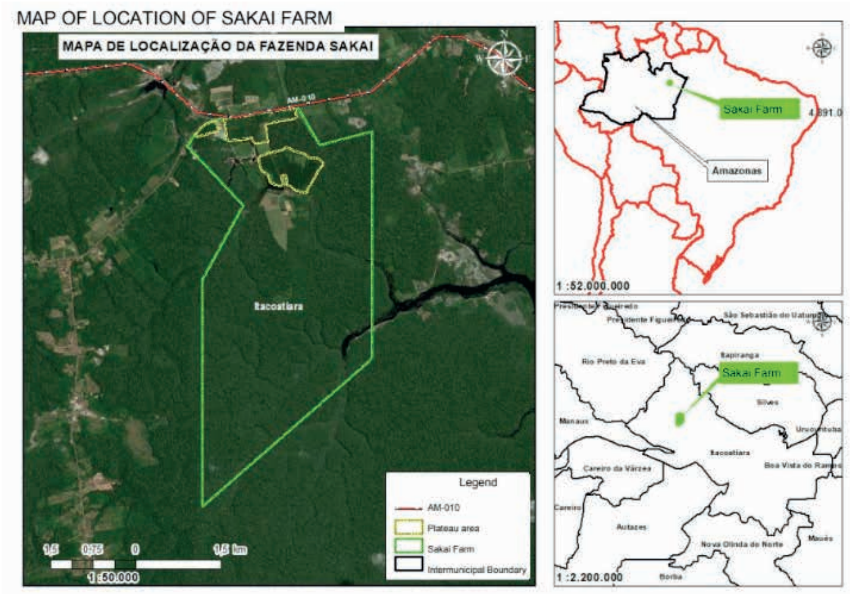

Figure 1. Location map of the study área. Highway AM 010, Km 172, Itacoatiara, Amazonas, Brazil.

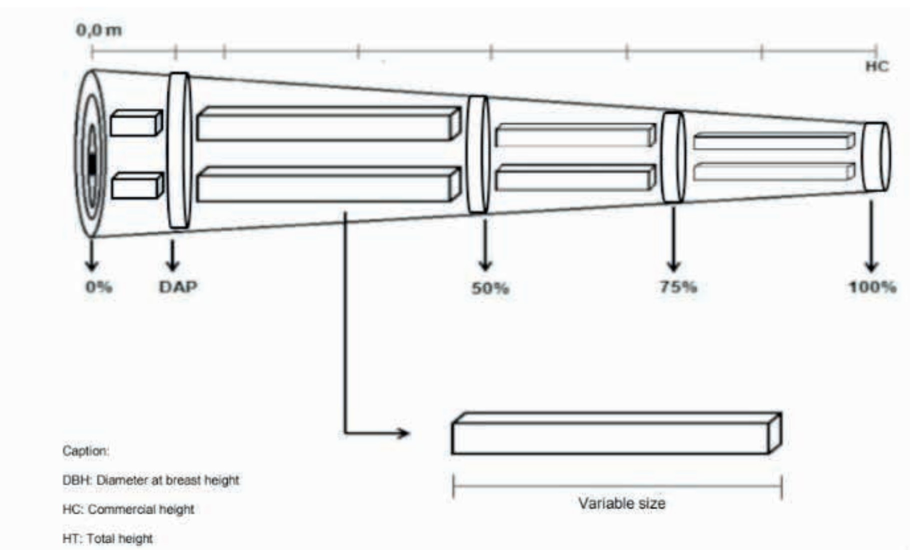

Figure 2. Schematic representation of the disks and plates removed for making the laboratory samples.

Property	Proof bodies	Dimensions (cm)
Compression parallel to the fibers	34	5,0 x 5,0 x 20,0
Static Flexion	36	5,0 x 5,0 x 76
Hardness Janka	33	5,0 x 2,0 x 15
Shear	36	5,0 x 5,0 x 6,3

Table 1. Quantity and dimensions of the samples used in the laboratory tests of the mechanical properties of *Swietenia macrophylla* wood.

randomized Analysis of Variance (ANOVA) was performed and, if there was a significant difference between the means, the Tukey test was performed. For the variables that did not present normality of the residues and/or homogeneity of the variance, the non-parametric Kruskal-Wallis test was used and, in case of significant difference, the post-hoc test was performed using the Dunn test. All analyzes considered a probability level of 95% (α = 0,05).

RESULTS

The five trees felled to make the specimens were numbered from one to five for identification and had diameters at breast height (DBH) equal to 11.3 cm (tree 1), 17.0 cm (tree 2), 26, 0 cm (Tree 3), 33.7 cm (Tree 4) and 41.4 cm (Tree 5). For the analysis of the physical properties of the wood, only four trees were considered, as the one with the smallest diameter did not allow the preparation of suitable specimens as described in NBR 7190 (ABNT, 1997), which were discarded. For the mechanical properties, it was possible to make specimens for all tests with the five felled trees.

PHYSICAL PROPERTIES

The average wood moisture varied between the trunks from 33.9% to 50.4%, while the average density varied between 0.46 and 0,55 g.cm^{-3} **(Tabela** 2).

The moisture variable met the assumptions of homogeneity and normality after logarithmic transformation, while the wood density variable did not meet these assumptions. For both variables, significant differences were found between the boles (Figure 3), with the average density of bole 2, with the lowest DBH, being lower than that of the others. The results for wood moisture show that stems 2 and 5 were statistically similar to each other, with higher values than stems 3 and 4.

MECHANICAL PROPERTIES

The average values of shear, hardness, compression and bending of the wood in each shaft are presented in Table 3.

The variables compression (MOE and TFM), flexion MOE, radial hardness and shear presented normal distribution and homogeneous variance, being possible the application of the F test for comparison between means and Tukey's test, when necessary. The other variables did not meet the assumptions of data normality and variance homecedasticity, requiring the use of non-parametric statistics for these cases.

MOE compression did not differ between stems, however TFM compression showed higher values in stems 3 and 4, with intermediate DAPs (Figure 4). The MOE and MOR flexion tests showed similar trends (Figure 4), in which the highest values are also observed in shafts 3 and 4, which are statistically equal, with the difference that number four also presents statistical equality with shaft 2 for flexion MOE and shafts 1 and 2 for MOR flexion. The bole number five, with the highest DBH, presents the lowest values for the two flexion tests.

Flexion showed behavior similar to compression, with a polynomial pattern of increase up to an intermediate DBH value (in this case 26.0 cm) and decrease up to the shaft with the largest diameter. This indicates that there is an optimal peak with the highest value of these variables in diameters between 25 and 35 cm.

The highest shear values were observed for stems 4 and 5, with the largest diameters. However, stem 4 was similar to the other three stems that had lower values (Figure 4).

The tests for hardness showed similar trends for the three faces of the specimens, with an increase in values according to the increase in DBH of the shaft (Figure 4), in which shafts 4 and 5 showed the highest values. It is

Number	DAP	Density (g.cm^{-3})	Moisture (%)
2	17,0	0,46	46,87
3	26,0	0,55	33,91
4	33,7	0,53	34,56
5	41,4	0,52	50,41

Table 2. *Swietenia macrophylla*'s wood density and humidity averages for each stem taken from a the equine stand in Central Amazon.

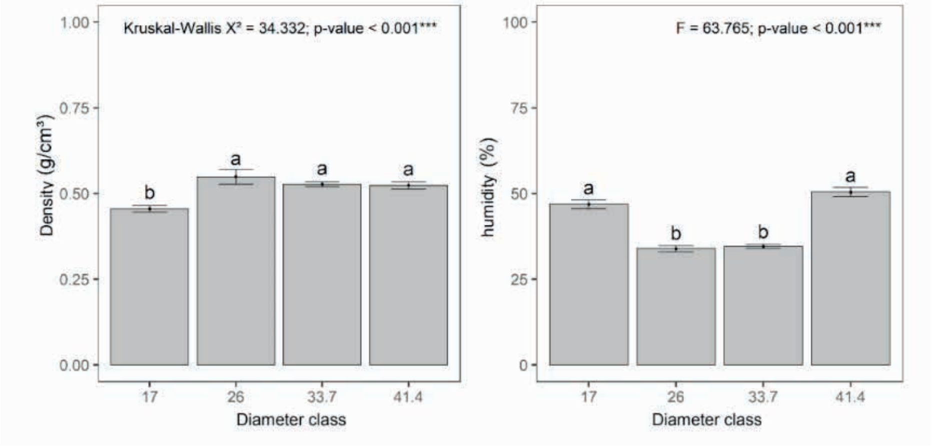

Figure 3. Density and humidity variation among stems of *Swietenia macrophylla* from an equine stand in Central Amazon.

Variable (Mpa)	shaft number (DAP, em cm)				
	1 (11.3)	2 (17.0)	3 (26.0)	4 (33.7)	5 (41.4)
Compression MOE	4820.13	5171.42	5566.50	5683.88	5379.16
Compression TFM	36.43	35.30	47.38	43.42	37.41
Flexion MOE	7483.91	9360.09	12272.40	11303.81	7722.59
Flexion MOR	69.63	71.74	91.23	81.76	60.19
Shear	9.22	9.65	8.24	10.27	12.76
Radial hardness	35.44	37.66	45.98	47.38	53.77
Tangential hardness	38.77	32.75	48.00	54.58	58.06
Transverse hardness	48.73	43.28	45.41	54.60	62.78

Table 3. *Swietenia macrophylla*'s mechanical properties averages for stems from a equine stand in Central Amazon.

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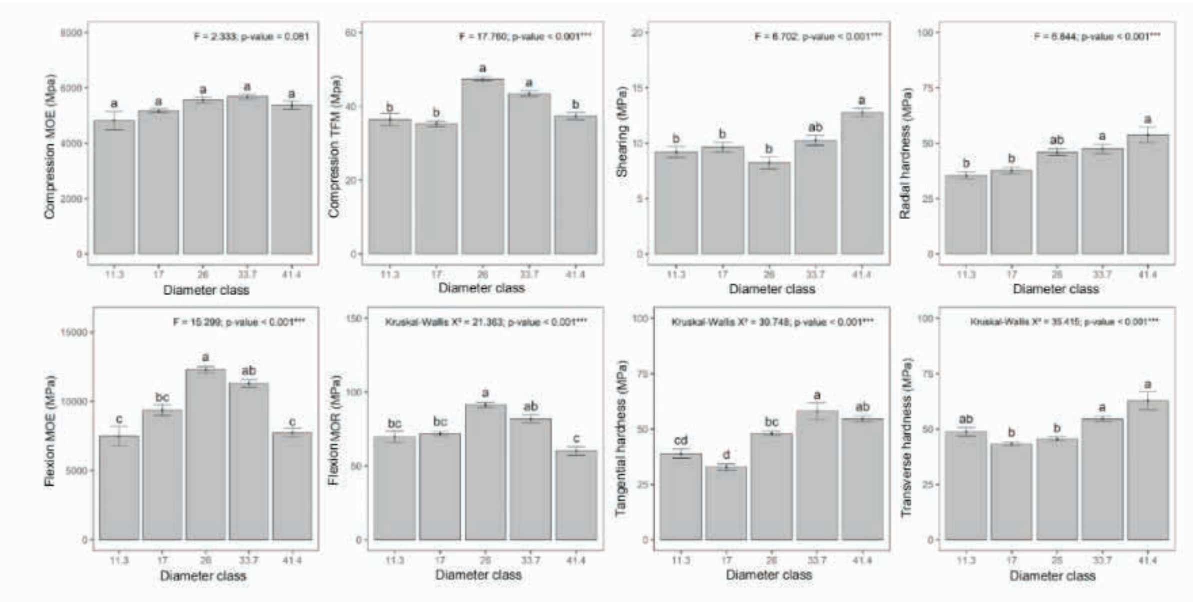

Figure 4. Variation between boles of the mechanical properties of wood in an even stand of *Swietenia macrophylla* in Central Amazon.

noteworthy that for radial hardness, shaft 3 is statistically equal to shafts 4 and 5, which also occurs with shaft 1 for transverse hardness.

DISCUSSION

PHYSICAL PROPERTIES

The moisture content found in the present study can be considered low compared to individuals from *Swietenia macrophylla* that are native in Latin American regions, where this variable ranges from 50.7% to 110.3% (Longwood, 1962). Juvenile wood is the result of the normal physiological growth process of the tree and fundamentally depends on age, planting environment and management (Passialis & Kiriazakos, 2004). This wood has a different quality from mature wood, the latter being normally considered to characterize the values of the properties of the species. In the present study, the age variable does not exert influence because it is considered only one age for all trees. Thus, it is believed that the difference observed for moisture between the evaluated stems is related to the microclimate and, mainly, to the planting management.

The basic density values found are slightly below the reference value described by the ITTO (International Tropical Timber Organization), which is 0,56 g.cm^{-3}**,** however, according to the established by the Laboratory of Forest Products of the Brazilian Forestry Service, which is 0.52 g.cm-^{3}. Other density studies for *Swietenia macrophylla* show a variation in the values: 0,52 g.cm^{-3} (Mainieri & Chimelo, 1989), 0,51 g.cm^{-3} (Fuentes & Hernandez, 2008) 0,47 g.cm^{-3} (Reboleto et al., 2017), 0,47 g.cm^{-3}, 0,55 g.cm^{-3}, 0,61 g.cm^{-3} (Langbour et al., 2011). This variation in basic density for the same species can be explained by the action of several factors that can modify this property: silvicultural practices, anatomical structure of the wood (fiber length, microfibrillar angle), age at planting (presence of juvenile and adult wood), among other anatomical elements (Benin et al., 2017).

Density is the property of wood that best expresses its quality for technological and industrial purposes, enabling decision-making regarding the most appropriate use for a given species (Araújo et al., 2016). From the evaluated stems, it is verified that from 26 cm of DBH the density values stabilize, indicating that this wood has potential for use in joinery, carpentry, furniture and construction in general.

MECHANICAL PROPERTIES

Studies indicate the correlation between wood density and its mechanical strength, in the sense that the higher the density, the higher mechanical strength values (Vidaurre et al., 2011). A general assessment of the mechanical properties of wood from *Swietenia macrophylla* show that the highest values are verified in the boles of larger diameters, or in those with intermediate diameters, which presented the highest values of basic density (Figure 3).

COMPRESSION AND FLEXION

The general average of TFM compression, of 39.99 Mpa, showed a value below that found in other studies for *Swietenia macrophylla*: 46,06 MPa (Kukachka, 1959), 45.86 Mpa (Reboleto et al., 2017), 55.1 Mpa, 40.6 Mpa and 45.1 Mpa (Langbour et al., 2011). However, when analyzing the collected shafts individually, it is verified that shafts 3 and 4, which presented statistical equality, present compression values within the range found in the cited studies (Table 3).

Comparing the results obtained with other species, it appears that the wood of *Swietenia macrophylla* has compression values less than *Khaya ivorensis, Khaya senegalensis* (França et al., 2015), *Hymenaea stilbocarpa* (Lahr et al., 2016) and *Cedrela odorata* (IBAMA, 2018). However, their values were superior to species such as: *Eucalyptus benthamii* (Benin et al., 2017), *Toona ciliata* (Trianoski et al., 2014) and *Schizolobium amazonicum* (Vidaurre et al., 2018).

The overall averages for the modulus of rupture (74.91 Mpa) and elasticity (9628.5 Mpa) are classified as high and medium respectively (IBAMA, 2018). The higher the modulus of elasticity, the greater the capacity of the wood to return to its standard state without displacement at the atomic level, thus causing plastic deformation of the wood, also called irreversible (Gallio et al., 2016), this way, stems 3 and 4, with intermediate diameters (DBH of 26 cm and 33.7 cm, respectively), evaluated in this study, showed resistance to deformation.

The reference values described according to the ITTO (International Tropical Timber Organization) for the modulus of rupture and elasticity for the wood of *Swietenia macrophylla* are 86.10 MPa and 9760.6 MPa, respectively, being considered high and close to data for this species in plantations in Central Amazonia. There is a variation in these values, MOR and MOE, respectively, verified in the literature: 61.78 MPa and 8825.29 MPa (Longwood, 1962), 81.08 MPa and 10617.93 (Kukachka, 1959) and 90.6 MPa and 9110.00 MPa (IPT, 1989), 74.40 MPa and 9628.56 MPa (Reboleto et al., 2017), 88.3 MPa, 70.7 MPa, 75.1 MPa and 10,960 MPa, 10,850 MPa, 11,100 MPa (Langbour et al., 2010).

The reason for the existence of higher values, especially when compared with wood from natural forests, for MOR and MOE is due to the fact that the anatomical and mechanical properties of the wood are differentiated due to the age of the wood, in which the adult portion presents characteristics superior and more homogeneous mechanics than the juvenile wood portion (Soriano et al., 2011).

SHEAR

The highest shear strength values found for shafts 4 and 5 were closest to the values described by IPT (1989), which cites the value of 10.9 MPa. Slooten & Souza (1993) and Moraes Neto (2009) found values of 8.7 MPa, which are below all the values found in the present study. Reboleto et al. (2017) reported a similar value (9.38 MPa) to those found for boles with diameters of up to 26 cm. Comparing with two other species, the shear strength of *Swietenia macrophylla* was lower than that verified for K. ivorensis (12.6 MPa) and K. senegalensis (18.6 MPa) (França et al., 2015), but higher than that described for: *Toona ciliata* (8,04 MPa) (Trianoski et al., 2014).

The shear strength of wood is directly proportional to its density, but mainly depends on the direction in which the effort is applied in relation to the growth rings. In the tangential plane, the main influence is due to the difference between the percentage of early and late woods that are broken. For the radial plane, there is a great influence of the wood radii, since woods with large and abundant radii have low shear strength compared to those with narrower radii and in smaller quantities (Moreschi, 2010).

HARDNESS

In general, the results presented in Table 2 are below the reference value described by IPT (1989), which is 49.4 MPa. Slooten & Souza (1993) found transversal and tangential values equal to 50.70 MPa and 42.66, respectively. The reference values according to ITTO for tangential and radial hardness are, respectively, 36.28 and 48.54 Mpa. Considering this variation, it appears that only stem 5, with the largest diameter, presents higher values in the three directions of the wood.

The Janka hardness values found for wood from *Swietenia macrophylla* are in line with what Klock (2000) states, in which he mentions that normally the hardness in the transverse direction is superior to the others. Benin et al. (2017) and Vidaurre et al. (2018) corroborate this fact, explaining that this behavior is possibly associated with the arrangement of the fibers in this sense and because it is an element that offers support and mechanical resistance to the wood.

CONCLUSIONS

The wood: *Swietenia macrophylla* has a high modulus of rupture, medium modulus of elasticity, medium shear strength, medium hardness, and medium fiber parallel compressive strength.

The quality of the 20-year-old plantations wood was compatible and favorable, comparatively, with material from other plantations, indicating the possibility of use for commercial purposes.

The intermediate classes showed higher density and lower moisture, demonstrating that, from the 26 cm class onwards, it is already possible to obtain an optimal wood density and the intermediate classes present a better response to drying. The intermediate classes also showed higher values of TFM compression, MOE flexion and MOR flexion, which demonstrates that the intermediate classes presented greater capacity of resistance and flexibility to deformation, while the superior classes presented higher values of tangential and transverse hardness and higher values of shear, which demonstrates greater density and probably a higher percentage of late wood.

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