Revista Ibero-Americana de Ciências Ambientais
Ibero-American Journal of Environmental Sciences

Jul 2022 - v.13 - n.7

ISSN: **2179-6858**

This article is also available online at:
www.sustenere.co

Wood properties and growth of Cunninghamia lanceolata: a natural alternative for treated Pinus sp. timber

Cunninghamia lanceolata (Chinese fir) is the main timber species in China with desirable wood properties and silviculture characteristics and has a high potential to be planted in Brazil. We aimed to assess selected wood properties of C. lanceolata from an experimental plantation in São Paulo, Brazil, since there is no information about this timber grown in Brazil. We also assessed the growth and increment rate of this plantation. Despite its low density (434 kg m-3), C. lanceolata timber has good mechanical properties, as well as low shrinkage. The studied timber showed superior properties than most Pinus sp. planted in Brazil and Eucalyptus grandis, especially when considering the strength to weight ratio. Together with its known high durability, our results show that C. lanceolata has potential for many applications from furniture to engineered products for structural purposes. The increment rate of the stand was low, probably because of the lack of management practices. But the species has high growth potential, reaching 41 m-3 ha-1 year-1 in China. After genetic improvement and under proper management, Cunninghamia lanceolata can be an ally of the Timber Industry in Brazil and other countries with adequate climate for the species and be used as a substitute to treated Pinus sp. wood.

Keywords: Chinese fir; Specific strength; MAI; Brazil.

Propriedades da madeira e crescimento de Cunninghamia lanceolata: uma alternativa natural para madeira tratada de Pinus sp.

Cunninghamia lanceolata (abeto chinês) é a principal espécie madeireira na China com propriedades de madeira e características silviculturais desejáveis ??e tem alto potencial para ser plantada no Brasil. Nosso objetivo foi avaliar as propriedades da madeira selecionada de C. lanceolata de uma plantação experimental em São Paulo, Brasil, uma vez que não há informações sobre essa madeira cultivada no Brasil. Também avaliamos a taxa de crescimento e incremento desta plantação. Apesar de sua baixa densidade (434 kg m-3), a madeira de C. lanceolata apresenta boas propriedades mecânicas, além de baixa retração. A madeira estudada apresentou propriedades superiores à maioria das espécies de Pinus sp. plantadas no Brasil e Eucalyptus grandis, principalmente quando se considera a relação resistência/peso. Juntamente com sua conhecida alta durabilidade, nossos resultados mostram que C. lanceolata tem potencial para muitas aplicações, desde móveis até produtos de engenharia para fins estruturais. A taxa de incremento do povoamento foi baixa, provavelmente pela falta de práticas de manejo. Mas a espécie tem alto potencial de crescimento, chegando a 41 m-3 ha-1 ano-1 na China. Após melhoramento genético e manejo adequado, Cunninghamia lanceolata pode ser aliada da Indústria Madeireira no Brasil e em outros países com clima adequado para a espécie e ser utilizada como substituta da madeira tratada de Pinus sp.

Palavras-chave: Abeto chinês; Força específica; MAI; Brasil.

Topic: **Ciências Florestais**

Reviewed anonymously in the process of blind peer.

Received: **02/07/2022**
Approved: **26/07/2022**

Bruno Monteiro Balboni
Universidade de São Paulo, Brasil
http://lattes.cnpq.br/4885362022915207
http://orcid.org/0000-0003-1617-5254
bruno.balboni@usp.br

Bruna de Araújo Braga
Universidade Federal do Paraná, Brasil
http://lattes.cnpq.br/5721582909946807
http://orcid.org/0000-0001-9361-4500
brunabrag4@gmail.com

Alessandra Silva Batista
Universidade de São Paulo, Brasil
http://lattes.cnpq.br/1281057231768001
http://orcid.org/0000-0003-4227-7801
alessandrabatista@usp.br

José Nivaldo Garcia
Universidade de São Paulo, Brasil
http://lattes.cnpq.br/9866736304143853
http://orcid.org/0000-0002-8289-9042
jngarcia@usp.br

Luciana Duque Silva
Universidade de São Paulo, Brasil
http://lattes.cnpq.br/4634971079104939
http://orcid.org/0000-0002-1765-9640
lucianaduques@usp.br

DOI: 10.6008/CBPC2179-6858.2022.007.0001

Referencing this:
BALBONI, B. M.; BRAGA, B. A.; BATISTA, A. S.; GARCIA, J. N.; SILVA, L. D.. Wood properties and growth of Cunninghamia lanceolata: a natural alternative for treated Pinus sp. timber. **Revista Ibero Americana de Ciências Ambientais**, v.13, n.7, p.1-9, 2022. DOI: http://doi.org/10.6008/CBPC2179-6858.2022.007.0001

INTRODUCTION

Cunninghamia lanceolata (Lambert) Hook., an evergreen conifer from the Cupressaceae family (FARJON, 2010), is recognized as the most important timber species from Southern China (ZHANG et al., 2013; ZHOU et al., 2020). Considered one of the fastest growing timber species, it is, according to Xu et al. (2016), a global resource for wood production. The species has been cultivated for more than 1000 years and its silviculture is extremely well developed (FAO, 1982).

C. lanceolata presents many desirable characteristics such as good form, fast growth, durable wood (FUNG, 1994; WEN et al., 2018; LIN et al., 2020), self-pruning, and low propensity to fork (COZZO, 1962). Due to these characteristics, *C. lanceolata* wood is widely used in China for different purposes, such as rail dormants, pulp, furniture (LI et al., 2015) buildings, coffins, poles, boats, particle boards and glulams, and the species represents 25% of all planted forest area in Southern China (DUAN et al., 2016).

A great advantage of *C. lanceolata* in relation to the majority of the conifers is its ability to sprout from the trunk basis (COZZO, 1962; FUNG, 1994), allowing the species to be managed under the coppicing scheme, a practice performed in China since the XII century (HUANG et al., citado por FUNG, 1994). Moreover, its wood presents high durability against xylophageous organisms (WEN et al., 2018), eliminating the need of chemical treatments.

Some studies point out that *C. lanceolata* has a high potential for plantations in Brazil (CARPANEZZI et al., 1988). Although it is a promising species and its wood displays highly desirable physical and mechanical properties, *C. lanceolata* lacks studies in Brazil, with very rare reports about growth and timber characteristics. Thus, the present study aims to assess some physical and mechanical properties as well as the increment rate of a second rotation experimental stand of *Cunninghamia lanceolata* planted in São Paulo State, Brazil.

MATERIALS AND METHODS

A 37-year *C. lanceolata* stand located at the Anhembi municipality (22.7884° S, 48.1310° W), São Paulo State, Brazil, was chosen to provide the material for the present study. The region, 480 m above the sea level, presents an average annual rainfall of 1307.2 mm, an average annual temperature of 22.3°C, and Koeppen Weather Class Aw.

The stand of 0.48 ha, is a test realized at the Anhembi Forest Experimental Station of the University of São Paulo, in order to check the adaptability and the potential of *C. lanceolata* in the region. The trees, in the quadratic occupation of 14.5 m² per individual, did not receive any management practice besides the clear-cut few years after the planting occurred and the best sprout selection 2 years later. After 35 years, the sprouts became trees of considerable size. Table 1 shows the diameter at breast height (DBH) of all 6 sampled trees, selected to be representative of the stand.

Table 1: Sampled trees and their respective diameter at breast height (DBH).

Tree	1	2	3	4	5	6
DBH (mm)	351	323	350	344	363	400

The 3-meter-long first log of each sampled tree, was processed in a vertical bandsaw with log carriage at the Wood Engineering Laboratory, University of São Paulo. From the central board - nominal thickness 55 mm - four samples per tree were extracted to test density, shrinkage, compression parallel to grain, shear, and static bending. The tests were chosen based on the main uses *C. lanceolata* can be applied to in Brazil.

The tests, proceeded in a universal testing machine with a capacity of 300KN, were done according to the Brazilian standard NBR 7190/1997 (ABNT, 1997), where specimens were defect-free and made of heartwood only. All of the following were evaluated: tangential, radial and volumetric shrinkage, density at 12% moisture content ($\rho_{12\%}$), resistance to compression parallel to grain (f_{c0}), shear strength (f_{v0}), and both moduli of rupture (f_M) and elasticity (E_{M0}) on static bending. With the ratio between strength and density, we calculated the specific strength in both compression and bending, as a way to compare the structural efficiency of the studied timber species.

Additionally, the adhesion strength of sapwood and hardwood through the shear test on the glue line ($f_{v0,g}$) was evaluated. We tested three wood combinations with 20 specimens each: sapwood-sapwood (s.s); sapwood-heartwood (s.h) and heartwood-heartwood (h.h). The test was conducted according to the ASTM D905 standard (ASTM, 2008). The wood was glued using single-component polyurethane with spread rate of 250 g m^{-2} and pressure of 0.7 MPa. After the adhesive cure, the specimens were kept in an acclimatization room at 20°C and 60% humidity until their mass stabilized, aiming the hygroscopic equilibrium at 12% moisture content (MC). Then, specimens were tested in the same universal testing machine described earlier. Both shear strength on the glue line and percentage of wood failure on the shear plane were computed for each specimen tested.

The three treatments were analyzed through an analysis of variance (ANOVA) followed by the Tukey test. To attend the theoretical prerogatives of the test (normal distribution and homogeneity of variances), the data was mathematically transformed applying the logarithm with base 10. To compare the shear strength of glued and solid heartwood, a T-test was applied. All graphs and tests were made using the R software (R CORE TEAM, 2022) and the confidence level adopted was 0.05 for all tests.

During the harvesting, each sampled tree had its total volume calculated. From their base, the log diameter was measured at each 2 m length until reaching a diameter of 100 mm. The Smalian formula was adopted to calculate the log volume, and then the volume of all the logs was summed up to compose the total tree volume. With the inventory data as well as the individual volume values, a linear regression was proceeded to project the volume for all stand trees and then to calculate its mean annual increment. To avoid possible influences from the surrounding stands, a boundary of two trees around the stand were excluded from the inventory, resulting in 0.3534 ha of inventoried area.

RESULTS AND DISCUSSION

Physical and mechanical properties

For a better comparison of the wood properties of *C. lanceolata* planted in São Paulo, Brazil, the values found in the present study (Table 2) were compared with *Araucaria angustifolia*, the commercial representative of Brazilian conifers, the two main forest cultures in Brazil, *Eucalyptus grandis* and *Pinus* sp. as well as *C. lanceolata* planted in China and New Zealand. When necessary, the values found in the literature were corrected to 12% moisture content (MC), using the equations provided by the NBR7190/1997 standard (ABNT, 1997).

Table 2: Wood properties of *C. lanceolata*, average values followed by standard deviation value between brackets (n = 24).

Species	$\rho_{12\%}$ (kg m^{-3})	f_{v0} (MPa)	f_{c0} (MPa)	f_{M0} (MPa)	E_{M0} (GPa)
C. lanceolata	434 (53)	8.14 (1.88)	39.1 (4.63)	77.3 (12.1)	11.47 (1.49)

Where: $\rho_{12\%}$ = density at 12% moisture content, f_{c0} = compression strength parallel to grain, f_{v0} = shear strength parallel to grain, f_{M0} = modulus of rupture on static bending; E_{M0} = modulus of elasticity on static bending

Table 3: Wood properties of *C. lanceolata* from different regions and commercial timbers found in Brazil.

Species	Country	$\rho_{12\%}$ (kg m^{-3})	f_{v0} (MPa)	f_{c0} (MPa)	f_M (MPa)	E_{M0} (GPa)
C. lanceolata	Brazil[1]	434	8.1	39.1	77.3	11.47
C. lanceolata	China[2]	368	-	31.3	70.9	10.7
C. lanceolata	China[3]	350	-	32.60	63.09	8.64
C. lanceolata	China[3]	540	-	56.33	93.34	10.59
C. lanceolata	N. Zealand[1]	385	-	28.8	-	7.4
E. grandis	Brazil[4]	487	7.0	42.1	75.6	9.69
A. angustifolia	Brazil[4]	535	9.9	45.1	93.3	14.15
P. elliottii	Brazil[4]	467	5.8	31.5	9.6	6.46
P. taeda	Brazil[5]	516	10.52	37.0	64.0	8.23
P.caribaea hondurensis	Brazil[5]	433	10.49	34.0	62.0	7.10
P. oocarpa	Brazil[5]	540	11.95	39.0	70.0	7.99

Where: $\rho_{12\%}$ = density at 12% moisture content, f_{c0} = resistance to compression parallel to grain, f_{v0} = resistance to shear parallel to grain, f_{M0} = modulus of rupture on static bending; E_{M0} = modulus of elasticity on static bending
Source:
[1] Present Study
[2] Yin et al. (2010)
[3] You et al. 2021; values from the lowest and highest density wood described
[4] IPT (1989); shear strength extracted from NBR 7190 (ABNT, 1997)
[5] Trianoski (2012)

Comparing the data in Table 3, it is possible to notice the superiority of *C. lanceolata* wood from Brazil in relation to those planted in China and New Zealand, except for densest wood reported by You *et al.* (2021). Although less dense than *E. grandis* and *P. elliottii*, the material from the present study showed superior strength values, again, with the exception of f_{c0}.

While *P. taeda* and *P. oocarpa* presented a higher density than *C. lanceolata* from Brazil, and *P. caribaeae* a lower density, on static bending, *C. lanceolata* has superior properties, equivalent values for compression and lower values for shear strength than all three cited *Pinus* species.

Although *A. angustifolia* and *C. lanceolata* have similar density values, the latter is inferior on all analyzed properties. However it is important to highlight that *C. lanceolata* is described as highly resistant to xylophageous organisms (WEN et al., 2018), an advantage in relation to the Brazilian *Araucaria*, considered by IPT (1989) as a low durability wood.

The specific properties of the studied material were higher than all the other species described in Table 3, besides *A. angustifolia*. In compression, the specific strength of *C. lanceolata* (90.1 MNm kg^{-1}) was

5% higher than *E. grandis* (86.4 MNm kg^{-1}) and 25% higher than *P. taeda* (71.7 MNm kg^{-1}). In bending, the differences are larger, where *C. lanceolata* (178.11 MNm kg^{-1}) presents values 14% higher than *E. grandis* (155.24 MNm kg^{-1}) and % than *P. taeda* (124.03 MNm kg^{-1}). It indicates a higher mechanical efficiency of *C. lanceolata* wood in comparison to our main planted timber species, which means the former needs a lower amount of weight to hold the same load.

Another highly relevant wood property concerning its application is the shrinkage in relation to the moisture content. Table 4 reveals the values found for radial, tangential and volumetric shrinkage of *C. lanceolata* from Brazil, China, New Zealand, as well as the same important species planted in Brazil already presented earlier.

Table 4: Wood shrinkage of *C. lanceolata* and forest species of relevance in Brazil

		shrinkage (%)			
species	country	radial	tangential	volumetric	source
C. lanceolata	Brazil	3.2	6.9	10.3	-
C. lanceolata	China	3.2	6.2	9.5	Fung (1993)
C. lanceolata	China	3.0	5.6	8.5	Fung (1993)
C. lanceolata	N. Zealand	3.0	6.8	10.0	Fung (1994)
E. grandis	Brazil	1.8	8.7	15.7	IPT (1989)
P. elliottii	Brazil	3.2	6.3	10.5	IPT (1989)
A. angustifolia	Brazil	5.3	7.8	13.2	IPT (1989)
P. taeda	Brazil	3.4	6.4	10.6	Trianoski (2012)
P.caribaea hondurensis	Brazil	4.0	5.7	9.0	Trianoski (2012)
P. oocarpa	Brazil	3.4	6.5	10.2	Trianoski (2012)

In Brazil, *C. lanecolata* wood has similar shrinkage than what was reported for this species in other countries, and had slightly higher values than *P. caribaea* and *P. oocarpa*. *E. grandis* has a considerably higher shrinkage than all the other species, which was expected since eucalypt woods are known for their high shrinkage levels (VERMAAS, 1995).

In terms of shrinkage, *C. lanceolata* planted in Brazil is of superior quality when compared to the 2 most planted species in the country and to its native representative of the commercial conifers. When compared to the *Pinus* species described by Trianoski (2012), *C. lanceolata* from Brazil is similar to *P. taeda* but has higher values than *P. oocarpa* and *P. caribaea*.

Adhesion

All specimens from the three treatments returned 100% of wood failure on the shear plane, indicating a very efficient adhesion. Thus, the differences found for shear strength can be attributed to the wood type, where heartwood was the strongest wood in shear, and sapwood the weakest (Figure 1). Heartwood specimens were 42% stronger than sapwood, while specimens combining sapwood and heartwood did not show difference with the other two treatments, with an intermediate $f_{v0,g}$ average.

When comparing glued to solid heartwood, there was no significant difference (*p*-value = 0.971), confirming the adhesion efficiency reported. Although wood extractives usually reduce adhesion strength (FRIHART et al., 2010), it was not observed in *C. lanceolata* heartwood. This result is an indication that *C. lanceolata* heartwood can also be used for engineered products with structural applications.

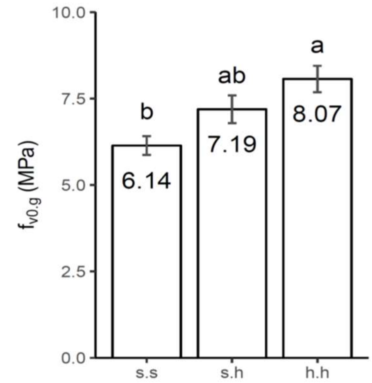

Figure 1: Shear strength on the glue line ($f_{v0,g}$) of the three treatments: sapwood-sapwood (s.s), sapwood-heartwood (s.h) and heartwood-heartwood (h.h). The same letter above the bars indicates no statistical difference when applying a ANOVA ($\alpha = 0.05$) to the transformed data using $\log_{10}$.

Growth

The average DBH found for the *C. lanceolata* stand was 276 mm, standard deviation 69.3 mm, and maximum and minimum values 490 mm and 135, respectively. The height was measured in 15% of the trees randomly selected, resulting in an average of 22.38 m, a standard deviation of 2.42m, maximum 25.5 m and minimum 18 m. The stand presented 14.5% of mortality, with 227 living trees and 33 dead trees.

For the tree volume projection, a linear regression with volume and DBH² ($R^2 = 0.66$) was applied (*volume* = -0.06454 + 7.67781[*DBH²*]). The stand volume estimation was 126.7 m³ in 0.3534 ha, or 358.44 m³.ha^{-1} in 35 years, resulting in a Mean Annual Increment (MAI) equal to 10.24 m³.ha^{-1}.year^{-1}.

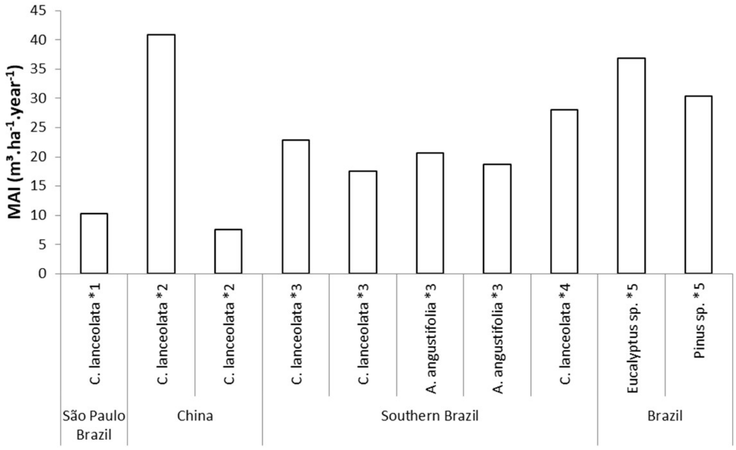

Figure 2: Mean Annual Increment (MAI) of *Cunninghamia lanceolata* from different regions and forest species of relevance in Brazil.
Source:
$^{*1-}$ Present Study; $^{*2-}$ China, Cooperative Group of Chinese Fir (1981), citado por Fung (1994); $^{*3-}$ Heinsdijk (1972); $^{*4-}$ Dobner Junior et al. (2016); $^{*5-}$ IBA.

On Figure 2, MAI of *C. lanceolata* from the present study, from plantations in China, New Zealand and in Southern Brazil are presented together with *A. angustifolia* plantations and the national average of *Eucalyptus* sp. and *Pinus* sp.

Although superior to the growth of 6 and 7.5 m³.ha^{-1}.year^{-1}in some regions of China (China, Cooperative Group of Chinese Fir, citado por FUNG, 1994), the MAI of *C. lanceolata* from São Paulo is far below the 40.9 ha^{-1}.year^{-1} described by the same cited author on the Chinese region of Guizhou. It is very important to emphasize that, while the stand from São Paulo did not receive any kind of provenance selection, nor an appropriate management, the species has been cultivated in its region of origin for more than a thousand years.

The stand from São Paulo also presents a slower growth rate in relation to other *C. lanceolata* plantations realized in Brazil (HEINSDJIK et al., 1962), 22.9 and 17.6 $m^3.ha^{-1}.year^{-1}$ at the age of 15 and 35 years-old, respectively, and 28.1 $m^3.ha^{-1}.year^{-1}$ at 21 years old (DOBNER JUNIOR et al., 2016). Cozzo (1962), who reported MAI values between 20 and 25 $m^3.ha^{-1}.year^{-1}$ in 30 years-old *C. lanceolata* stands, highlights the higher edaphic requirements of the Brazilian *A. angustifolia* in relation to the Chinese *C. lanceolata*.

The great discrepancy of the growth rates on the São Paulo plantation in relation to the other Brazilian *C. lanceolata* stands, is clearly a consequence of the inappropriate and near absence of management practices. If we look at *Eucalyptus* sp., the main forest culture in Brazil, its MAI was around 8 $m^3.ha^{-1}.year^{-1}$,in the early 1970's, and today it has reached a national average of 36.8 $m^3.ha^{-1}.year^{-1}$. The main cause for that is the development of many management techniques together with a genetic improvement that aimed to minimize physical and biological restrictions of eucalypts in Brazil (GONÇALVES et al., 2013), reaching MAI values superior to 80 $m^3.ha^{-1}.year^{-1}$ (GAVA et al., 2008).

The high increment levels observed in China show the growth potential of *C. lanceolata*. With the adoption of adequate management practices, such as spacing, fertilization and thinning, *C. lanceolata* will certainly present a higher growth in relation to the São Paulo stand. In China, a genetic improvement program has returned considerable timber yield gains, between 25 and 5% after each of the four breeding program generations (ZHOU et al., 2020). Cloning practices have been used in the *C. lanceolata* silviculture for at least 800 years (MINGHE et al., 1999), so a breeding program similar to what was done in Brazil with *Eucalyptus* in the 1970's (ASSIS et al., 2011), might return *C. lanceolata* clones adapted to the Brazilian conditions and reach the 40.9 $m^3.ha^{-1}.year^{-1}$ yield reported in China.

Potential uses and applications

The properties observed in *C. lanceolata* wood planted in Brazil are in agreement with those described on the literature for plantations in other countries. Besides desirable wood properties, *C. lanceolata* has also silvicultural benefits; it combines some advantages of *Eucalyptus* sp. (fast growth, self-pruning, resprouting) with those from *Pinus* sp. (absence of growth stress, low-density but strong wood), with the additional benefit of high wood durability. Hence, *C. lanceolata* heartwood is a natural substitute for treated *Pinus* sp. wood, with no need for chemical treatments, reducing production time and costs, as well as being more environmental friendly. In Brazil, *C. lanceolata* timber has potential for the same applications reported in China: construction, railroad ties, furniture (LI et al., 2015). The crescent adoption of the light wood frame buildings (SOTSEK et al., 2018) and mass timber products in Brazil might also be an application for *C. lanceolata*, uses mainly occupied by *Pinus* sp timber.

The possibility of adopting a coppicing management without pruning branches provides additional economic advantages to *C. lanceolata* in relation to classic *Pinus* sp. silviculture, such as reduced costs for establishing the stand, fast initial growth and earlier payout (MINGHE et al., 1999). The favourable wood and silvicultural characteristics can turn *Cunninghamia lanceolata* into an important source of commercial timber in Brazil and other countries with adequate climate, supplying high quality timber in short cycle rotations specially to replace different markets occupied today by treated *Pinus* sp. timber.

CONCLUSIONS

C. lanceolata timber is a high quality raw material, with superior physical and mechanical properties than the main planted forest species in Brazil. With a high adhesion strength and efficiency, it has potential to be applied for the manufacture of engineered wood products with natural durability and high strength to weight ratio.

Although the studied species presented a low increment rate, it can be genetically improved, receive an appropriate management and make considerable gains in growth, with potential to achieve the highest MAI described in China.

If improved and cultivated in the proper manner, *Cunninghamia lanceolata* can be a great ally to the Brazilian timber industry, mainly as a natural substitute for treated Pine timber, with the possibility to be managed by coppicing, which would dispense the need to replant the stand.

REFERENCES

ABNT. Associação Brasileira de Normas Técnicas**. NBR 7190**: Projeto de Estruturas de Madeira. Rio de Janeiro: ABNT, 1997.

ASSIS, T.; RESENDE, M.. Genetic improvement of forest tree species. **Crop Breeding and Applied Biotechnology**, p.44-49, 2011. **DOI**: http://doi.org/10.1590/S1984-70332011000500007

ASTM. American Society for Testing and Materials. ASTM D 5751: Adhesives used for laminate joints in nonstructural lumber products. Pennsylvania: ASTM, 2005.

CARPANEZZI, A. A.; PEREIRA, J. C. D.; CARVALHO, P. E. R.; REIS, A.; RODRIGUES, A. R.; ROTA, E.; STURION, J . A.; RAUEN, M. J.; SILVEIRA, R. A.. **Zoneamento ecológico para plantios florestais no Estado de Santa Catarina**. Embrapa - CNPF, 1988.

COZZO, D.. Las plantaciones de *Cunninghamia lanceolata* realizadas en el Brasil. Antecedentes en la Argentina. **Revista Forestal Argentina**, v.6, n.2, p.37-43, 1962.

DOBNER JUNIOR, M.; TRAZZI, P. A.; MACHADO, S. A.; HIGA, A R.. Aspectos dendrométricos e silviculturais de um povoamento de *Cunninghamia lanceolata* no Sul do Brasil. **Floresta**, Curitiba, v.47, n.1, p.1-9, 2017. **DOI:** http://dx.doi.org/10.5380/rf.v47i1.43562

DUAN, H.; CAO, S.; ZHENG, H.; HU, D.; LIN, J.; LIN, H.; LI, Y.. Variation in the growth traits and wood properties of Chinese fir from six provinces of southern China. **Forests**, v.7, n.9, p.192, 2016. **DOI**: http://doi.org/10.3390/f7090192

FAO. **Forestry in China**. Forestry Paper No.35. Rome: FAO, 1982.

FARJON, A.. **A Handbook of the World's Conifers**. Brill, 2010.

FRIHART, C. R.; HUNT, C. G.. Adhesives with wood materials: bond formation and performance. In: ROSS, R. J.. **Wood Handbook**. USDA Forest Service, Forest Products Laboratory. Centennial, 2010. p.509.

FUNG, L. E.. A literature review of *Cunninghamia lanceolata*. **The Commonwealth Forestry Review**, p.172-192, 1994.

FUNG, L. E.. Wood properties of new zealand-grown *Cunninghamia lanceolata*. **New Zealand Journal of Forestry Science**, v.23, n.3, p.324-338, 1993.

GAVA, J. L.; GONÇALVES, J. L. D. M.. Soil attributes and wood quality for pulp production in plantations of *Eucalyptus grandis* clone. **Scientia Agricola**, v.65, p.306-313, 2008. **DOI**: http://doi.org/10.1590/S0103-90162008000300011

GONÇALVES, J. L. M.; ALVARES, C. A.; HIGA, A. R.; SILVA, L. D.; ALFENAS, A. C.; STAHL, J.; EPRON, D.. Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. **Forest Ecology and Management**, v.301, p.6-27, 2013. **DOI**: http://doi.org/10.1016/j.foreco.2012.12.030

HEINSDIJK, D.. **Forest in Southern Brazil**. Rio de Janeiro: Instituto Brasileiro de Desenvolvimeto Florestal, 1972.

HEINSDJIK, D.; SOARES, R. O.. Plantações de coníferas no Brasil: estudo preliminar sobre volumes e rendimentos da *Araucaria angustifolia*, *Cryptomeria japonica*, *Cunninghamia* *lanceolata* e *Pinus elliottii*. **Boletim Serviço Florestal Setor de Inventários Florestais**, Rio de Janeiro, n.5, p.1-75, 1962.

IPT. Instituto de Pesquisas Tecnológicas do Estado de São Paulo. **Fichas de características das madeiras brasileiras**. 2 ed. São Paulo. IPT, 1989.

LI, Y. Q.; DENG, X. W.; HUANG, Z. H.; XIANG, W. H.; YAN, W. D.; LEI, P. F.; PENG, C. H.. Development and evaluation of models for the relationship between tree height and diameter at breast height for Chinese-fir plantations in subtropical China. **PloS One**, v.10, n.4, p.e0125118, 2015. **DOI:** http://doi.org/10.1371/journal.pone.0125118

LIN, E.; ZHUANG, H.; YU, J.; LIU, X.; HUANG, H.; ZHU, M.; TONG, Z.. Genome survey of Chinese fir (*Cunninghamia lanceolata*): Identification of genomic SSRs and demonstration of their utility in genetic diversity analysis. **Scientific Reports**, v.10, n.1, p.1-12, 2020. **DOI**: http://doi.org/10.1038/s41598-020-61611-0

MINGHE, L.; RITCHIE, G. A.. Eight hundred years of clonal forestry in China: I. traditional afforestation with Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.). **New Forests**, v.18, p.131-142, 1999. **DOI:** http://doi.org/10.1023/A:1006558900234

R CORE TEAM. R development core team. **R**: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2022.

SOTSEK, N. C.; SANTOS, A. P. L.. Panorama do sistema construtivo light wood frame no Brasil. **Ambiente Construído**, v.18, n.3, p.309-326, 2018. **DOI**: http://doi.org/10.1590/s1678-86212018000300283

TRIANOSKI, R.. **Avaliação da qualidade da madeira de espécies de pinus tropicais por meio de métodos convencionais e não destrutivos**. Tese (Doutorado) - Universidade Federal do Paraná, Curitiba, 2012.

VERMAAS, H. F.. Drying eucalypts for quality: material characteristics, pre-drying treatments, drying methods, schedules and optimization of drying quality. **Suid-Afrikaanse Bosboutydskrif,** v.174, p.41-49, 1995. **DOI:** http://doi.org/10.1080/00382167.1995.9629877

WEN, H.; DENG, X.; ZHANG, Y.; WEI, X.; WANG, G.; ZHOU, B.; ZHU, N.. Cunninghamia lanceolata variant with red-heart wood: a mini-review. **Dendrobiology**, v.79, p.156-167, 2018. **DOI**: http://dx.doi.org/10.12657/denbio.079.014

XU, H.; CAO, D.; FENG, J.; WU, H.; LIN, J.; WANG, Y..Transcriptional regulation of vascular cambium activity during the transition from juvenile to mature stages in *Cunninghamia lanceolata*. **Journal of Plant Physiology**, v.200, p.7-17, 2016. **DOI:** http://doi.org/10.1016/j.jplph.2016.06.003

YIN, Y.; NAGAO, H.; LIU, X. AND NAKAI, T.. Mechanical properties assessment of *Cunninghamia lanceolata* plantation wood with three acoustic-based nondestructive methods. **Journal of Wood Science**, v.56, n.1, p.33-40, 2010. **DOI:** http://doi.org/10.1007/s10086-009-1067-8

YOU, R.; ZHU, N.; DENG, X.; WANG, J.; LIU, F.. Variation in wood physical properties and effects of climate for different geographic sources of Chinese fir in subtropical area of China. **Scientific reports**, v.11, n.1, p.1-11, 2021. **DOI**: http://doi.org/10.1038/s41598-021-83500-w

ZHANG, X.; DUAN, A.; ZHANG, J.. Tree biomass estimation of Chinese fir (*Cunninghamia lanceolata*) based on Bayesian method. **Plos One**, v.8, n.11, p.e79868, 2013. **DOI**: http://doi.org/10.1371/journal.pone.0079868

ZHOU, B.; PENG, D.; ZHAO, Q.; YANGNAN, S.; YANG, S.; YANG, F.; DENG, X.. Improvements in timber production of Chinese fir (*Cunninghamia lanceolata*) per unit forest area in China via tree breeding: Status and challenges. **Dendrobiology**, v.83, p.45-51, 2020. **DOI**: http://dx.doi.org/10.12657/denbio.083.004