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EFFECT OF GENETIC MATERIAL AND FERTILIZATION ON ESTIMATING THE DRYING POTENTIAL OF *Tectona grandis* Linn F.

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Resumo

A secagem é uma etapa fundamental no processo de produção da madeira serrada. A definição de variáveis que afetam a qualidade do processo como temperaturas inicial, final e potencial de secagem depende do conhecimento tecnológico da madeira, bem como da experiência sobre o processo desenvolvido para determinada espécie. Pensando nisso, desenvolvemos um experimento com a madeira de quatro materiais genéticos/procedências (3 clones e 1 seminal) da espécie *Tectona grandis* cultivadas com e sem adubação, a fim de estimar e avaliar esses parâmetros utilizados na elaboração de programas. Os valores das temperaturas inicial e final e potencial de secagem foram estimados a partir da metodologia da secagem drástica, onde se avaliou a taxa e escore de defeitos (rachaduras e colapso). Além dos parâmetros da secagem, as propriedades físicas da madeira também foram avaliadas. Os resultados mostraram que a procedência e a adubação não afetaram os parâmetros temperaturas inicial e final. Contudo, o potencial de secagem foi afetado significativamente pela associação dos tratamentos. Observou-se que os potenciais de secagem da madeira de determinados materiais genéticos foram afetados positivamente pela adubação. Os materiais provenientes de áreas adubadas apresentaram as menores densidades básicas, maiores teores de umidade inicial e maiores taxas de secagem.
Palavras-chave: Teca, secagem drástica, curva de secagem

Abstract

Drying is a fundamental step in the lumber production process. The definition of variables that affect the quality of the process, such as initial and final temperatures as well as drying potential, depends on the known technological knowledge of the wood, as well as on the experience of the drying process developed for a particular species. With this in mind, we developed an experiment using wood from four genetic materials (three clones and one seminal) of the species *Tectona grandis* cultivated with and without fertilization. This was done to estimate and evaluate the parameters used in the explanation of drying programs. The values of the initial and final temperatures, and those of the drying potentials, were estimated using the drastic drying methodology, which evaluates the drying rate and defect score (cracks and collapse). In addition to the drying parameters, the physical properties that affect the drying performance were also evaluated. The results show that origin and fertilization did not affect the initial and final temperatures. However, the potential drying parameters were significantly affected by the combination of treatments. Furthermore, the wood drying potential of certain genetic materials was positively affected by fertilization. Finally, the material from the fertilized areas had the lowest basic densities, the highest initial moisture content, and the highest drying rates.
Keywords: Teak, drastic drying, drying curve

INTRODUCTION

Tectona grandis Linn F. (teak), of the Lamiaceae family, is one of the best-known and highly valued tropical wood species. This wood is considered to be moderately hard and has good machining properties (MIRANDA *et al*., 2011). It is used in a variety of applications, particularly in luxury furniture and shipbuilding. In addition, there is the possibility of marketing its production from the first thinning. Furthermore, teak wood performs well during drying (BRAZ *et al.*, 2015; MIRANDA *et al.*, 2011), and is widely desired for export as it guarantees high financial returns. However, this return is dependent on the final quality of wood. Factors such as genetic material and soil fertilization influence the development of wood and affect the quality of its use (VIEIRA *et al*., 2018).

Drying can be defined as a dynamic balance between the heat transfer from the air to the wood, the evaporation surface of the wood, the diffusion of moisture through the wood, and the mass flow of free water. Drying reduces the moisture content of green wood, and if continued, the cell walls will become unsaturated. The main objective of drying is to promote a balance between the speed of water evaporation from the surface of the wood, the internal rate of movement (both heat and humidity), and the reactions that the wood undergoes during the process. These factors are all evaluated and modified, to promote the fastest possible drying rate with a low level of loss or an acceptable quality standard for the desired product (JANKOWSKY, 2011). However, when drying is carried out improperly, defects generated by the movement of fluids in the wood are caused, thereby reducing the value of the product.

High temperatures reduce the drying time by providing an increased drying rate mainly for the removal of diffused water. Notably, the speed of air circulation has a significant influence on heat transfer to the wood surface, as well as on the transfer of water vapor mass from the surface to the medium, thereby increasing the capillary water's rate of removal. Drying at high initial temperatures quickly and without uniformity can result in wood defects (YANG; LIU, 2018; NASCIMENTO *et al.*, 2019). The choice of drying parameters influences the drying time and the quality of the dry material. It is possible to reduce the drying time and the incidence of defects when the process is conducted using the correct parameters. According to Bonduelle *et al.* (2015), the physical properties of wood also influence its technological behavior when it is directly reflected in the industrialization process. This is highlighted by its density and retractability, which are characteristics that present variations in the radial and longitudinal directions of tree trunks. Amer *et al.* (2020) stated that the resistance to water transfer in wood depends on its density and anatomical direction. According to Monteiro and Lima (2020), anatomical elements influence the flow of water during drying, as the length and diameter of the vessel have a positive effect on water flow via capillarity.

The drastic drying method is used to obtain parameters for developing drying programs that are more suitable for the wood under study (JANKOWSKY, 2011). A drying program for wood is defined by adjusting it to the characteristics of the wood being studied, its specific mass, propensity to the occurrence of defects, and the desired quality standard for essential materials after the procedure. The quality of wood is related to its ability to meet the requirements necessary to manufacture a product. Its quality can also be evaluated as the combination of physical, chemical, anatomical, and structural properties of the tree or its parts that lead to maximum utilization and applicability for specific purposes (MEDEIROS *et al*., 2016).

The properties of the wood to be dried also influence the drying rate obtained (SUSIN *et al.*, 2014). Thus, the drying rate or speed depends on factors inherent to the drying process (temperature, relative humidity, air circulation speed between wood piles, and drying potential), as well as on factors intrinsic to the wood used (species, anatomy, permeability, and chemical constitution).

Drying, when conducted incorrectly, can generate high loss, wood with physical properties that are unsuitable for use, and financial losses. To ensure quality in the drying process, it is necessary to use the correct values of these variables to conduct drying that yields the best possible result. The use of models to accurately and quickly predict the values of these variables is essential. The objective of this study was to estimate and evaluate the parameters obtained to carry out drying programs for *T. grandis* wood of different genetic materials, with and without fertilization.

MATERIAL AND METHODS

Characterization of the material

The study material was obtained from homogeneous plantations located in the cities of Redenção (PA) and Santa Maria das Barreiras (PA). Forty *T. grandis* trees were collected at 12 years of age, and were distributed among eight treatments, with five trees in each, selected according to the genetic material and planting condition (with or without fertilization). The treatments with fertilization received cover fertilization with NPK 6-42-00 B + Zn. In the field, data on the diameter and height of each tree were collected, and the means per treatment are shown in Table 1.

Table 1. Condition of the evaluated treatments.
Tabela 1. Condição dos tratamentos avaliados.

Treatment	Fertilization	Origin	Diameter (cm)	Commercial height (m)
T1	A1	Clone 1 (C1)	29.37 (8.47)	11.00 (14.37)
T2	A1	Clone 2 (C2)	31.88 (9.19)	10.50 (10.66)
T3	A1	Clone 3 (C3)	30.50 (7.53)	10.80 (10.14)
T4	A1	Seed (Se)	30.44 (10.78)	9.29 (26.94)

T5	A2	Clone 1 (C1)	29.72 (11.00)	9.75 (6.63)
T6	A2	Clone 2 (C2)	29.65 (4.68)	8.16 (9.41)
T7	A2	Clone 3 (C3)	29.72 (13.59)	9.91 (8.43)
T8	A2	Seed (Se)	26.02 (15.64)	7.37 (22.24)

A1: With fertilization; A2: No fertilization. The values in parentheses refer to the coefficient of variation (%).

Drastic drying

The drastic drying methodology proposed by Jankowsky (2009) was used for drying wood. This methodology is a tool for obtaining parameters for assessing the performance of drying programs. It is based on the theory that the use of small samples, subjected to drying at high temperatures (100ºC), leads to behavior that is proportional to that observed in conventional drying. Sixty specimens were prepared per treatment for the drying test. Each tree was represented by four tangential samples of the core region, taken from the toretes from the base, from which the specimens were obtained (Figure 1). To avoid moisture loss, the specimens intended for drastic drying, and density and moisture evaluations, were properly identified and submerged in water until the testing began.

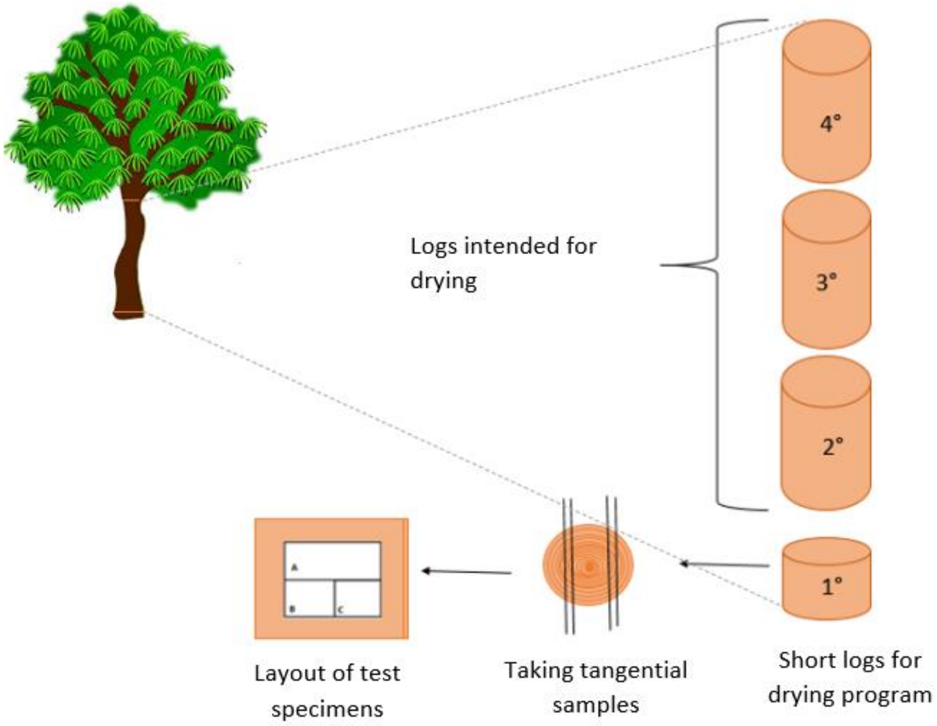

Figure 1. Sampling scheme of the specimens for drastic drying. A = Sample for oven drying at 100 ° C (100 × 50 × 10 mm); B = Sample for determining basic density (50 × 50 × 10 mm); C= Sample for determining the initial moisture content (50 × 50 × 10 mm).

Figura 1. Esquema de amostragem dos corpos de prova secagem drástica. A= Amostra para a secagem em estufa a 100°C (100 × 50 × 10 mm); B= Amostra para determinação da densidade básica (50 × 50 × 10 mm); C= Amostra para determinação do teor de umidade inicial (50 × 50 × 10 mm).

Using the drastic drying methodology, parameters such as the initial drying temperature (Ti), final temperature (Tf), and drying potential (Ps) were obtained. These are necessary for the elaboration of a drying program. The variables considered in the test included drying time, the speed at which drying occurred (i.e., drying rate), top cracks, and the rate of collapse occurrence.

To calculate the Ti, Tf, and PS parameters, Equations 1, 2, and 3 were used.

$$\mathrm{Ti} = 27{,}9049 + 0{,}7881\mathrm{T2} + 419{,}0254\mathrm{V1} + 1{,}9483\mathrm{R2} \quad (1)$$

$$\mathrm{Tf} = 49{,}2292 + 1{,}1834\mathrm{T2} + 273{,}8685\mathrm{V2} + 1{,}0754\mathrm{R1} \quad (2)$$

$$\mathrm{PS} = 1{,}4586 - 30{,}4418\mathrm{V3} + 42{,}9653\mathrm{V1} + 0{,}1424\mathrm{R3} \quad (3)$$

where T2 is the drying time of initial humidity up to 30% (h); V1 is the drying rate of initial humidity up to 5% (g/cm²·h); V2 is the drying rate of initial humidity up to 30% (g/cm²·h); V3 is the drying rate from 30% to 5% humidity (g/cm²·h); R1 is the intensity of cracks from initial humidity up to 5%; R2 is the intensity of the initial humidity cracks up to 30%; and R3 is the crack intensity from 30% to 5%.

Drying curve

The curves were obtained from the initial moisture content, taken at each interval for material mass collection, to the stabilization of the sample mass. The frequency of the weighing scans for each sample was every 30 min. The moisture content of the dry base was calculated from the mass obtained for each weight. Furthermore, wood moisture content was determined according to NBR 7190 (ABNT, 1997).

Drying rate (Capillarity, Diffusion, and Total)

The data on the drying speed and elapsed drying time up to 0% of *T. grandis* wood were used to calculate the drying rate based on the loss of water mass taken every 30 min during the process (Equation 4).

$$Ts = \frac{Mágua}{(t.A)} \qquad (4)$$

where Ts is the drying rate for a given moisture range (kg/cm2·h), water is the mass of water removed from the wood (kg), t is the drying time (h), and A is the evaporation area (cm²).

The evaporation area was determined by considering each test body to be a rectangular prism (Equation 5). The drying rate of the wood in each treatment was calculated for moisture intervals ranging from green humidity to fiber saturation point FSP, and from FSP to dry wood.

$$AT = 2(a.b + a.c + b.c) \qquad (5)$$

where TA is the total area (cm²); and a, b, and c are measurements of the faces of the prismatic test body (cm).

Drying defects

Crack defects during drastic drying were evaluated through the periodic analysis of their occurrence and intensity. This was done using calibration slides and calipers to obtain the dimensions (length and width) of the defects in the sample. These values were used to define the scores for the defects in the sample.

The score assigned to the top crack drying defect, varies between Note 1 (absence of defect); Note 2 (CR < 5.0 and LR < 0.5); Note 3 (CR > 5.0 and LR < 0.5); Note 4 (CR < 5.0 and 0.5 < LR < 1.0); Note 5 (CR > 5.0 and 0.5 < LR < 1.0); and Note 6 (CR > 5.0 and LR > 1.0), where the cr = crack length (mm) and LR = crack width (mm). A higher note indicates a higher occurrence of this defect. This analysis was performed throughout the drying process, at the intervals where periodic weighing was performed, and the presence of cracks was evaluated.

Collapse was evaluated by measuring the variations in the thickness of the sample, and measurements were taken with a caliper at the beginning of drying, considering the sample to be a perfectly rectangular prism. At the end of the process, the point of greatest deformation owing to collapse was observed to obtain the final measurements. For this, the sample was sectioned in half to ensure that the area most affected by the defect was identified and measured correctly.

The intensity of the collapse defect was distributed in four notes, classified as Note 1 (absence of the defect), Note 2 (From < 0.25), Note 3 (0.25 < From < 0.5), Note 4 (0.5 < From < 1.0); or Note 5 (From > 1.0), where De = variation in sample thickness (mm). For cracks, the higher the score, the higher the occurrence of this defect.

Physical properties

To estimate the fundamental parameters of the drying programs, analyses of the physical properties of the wood were not performed directly; however, we conducted an additional analysis of these results under the same climatic conditions as the drastic drying process.

Basic density and volumetric contraction were determined according to the NBR 11,941 standard (ABNT, 2003).

Calculation of the anisotropy coefficient was obtained according to Equation 6:

$$CA = CT/CR \qquad (6)$$

where CA, CT, and CR are the anisotropy coefficient, tangential contraction, and radial contraction, respectively.

Regarding the anisotropy coefficient, the criteria for the classification of wood were considered according to Durlo and Marchiori (1992). Specifically, the wood is considered excellent if it has values between 1.2 and 1.5; it is considered normal if it has values between 1.5 and 2.0; and it is considered bad if it has values above 2.0.

Statistical analysis

The data were previously subjected to an analysis of verification of the normality of the residues and homoscedasticity of the variance. Because the parameters of initial and final temperature did not meet the basic assumptions for ANOVA, the Kruskal–Wallis nonparametric test was performed. The PS parameter and the physical properties of the wood were evaluated in a factorial design with two factors (origin and fertilization) being considered. These factors, comprising four levels of origin (C1, C2, C3, and Se), two levels of fertilization (A1 - with fertilization and A2 - without fertilization), and the interaction between them, were assesed through the analysis of variance and test of means using Tukey’s significant 5% probability of error, in the statistical program R.

RESULTS

According to the Kruskal–Wallis test, the ti and tf obtained via drastic drying did not differ between the treatments. However, the PS parameter showed significant differences between the treatments and significant interactions between the evaluated factors (Table 2). In light of the significant interaction, the unfolding was performed. For the folding of origin in the fertilization levels, both (A1 and A2) showed statistically significant differences. For the unfolding of fertilization:origin interaction, levels C1, C2, and Se were significant.

Table 2. ANOVA for drying potential data.
Tabela 2. ANOVA para dados de potencial de secagem.

	GL	SQ	QM	Fc	Pr.Fc
Origin	3	0.323	0.1077	6.677	0.00125*
Fertilization	1	0.484	0.484	30.016	0.00000493*
Origin:Fertilization	3	0.296	0.0987	6.119	0.00207*
Residuals	32	0.516	0.0161		

It is possible to observe that in the pairs of treatments T1-T5, T2-T6, and T4-T8 of the same genetic material, the effect of fertilization was beneficial. Treatments T2 and T4, which were subjected to fertilization, showed a significant increase in the PS of the wood. For the T3-T7 treatment, fertilization did not influence the drying performance (Table 3).

Table 3. Treatment drying parameters.
Tabela 3. Parâmetros de secagem por tratamento.

Treatment	Ti	Tf	PS*
T4 (Se-C)	51.5	75.7	2.98 a
T2 (C2-C)	50.2	74.4	2.88 ab
T7 (C3-S)	49.4	74.1	2.78 abc
T3 (C3-C)	48.6	74.0	2.76 abc
T1 (C1-C)	47.3	72.3	2.64 bcd
T6 (C2-S)	47.3	72.4	2.62 bcd
T8 (Se-S)	46.4	70.8	2.52 cd
T5 (C1-S)	45.5	70.3	2.46 d

Where: Ti= Initial temperature; Tf: final temperature; PS= Drying potential. *: Means followed by the same letter in the column do not differ according to Tukey's test significant 5% probability of error.

Although all curves presented behavior that was consistent with what was expected in the drying phases, the behavior varied between treatments, especially with regard to phase one of the free water outlet between the initial moisture content of the wood and its saturation point of fibers (FSP), which was 30% on average (Figure 2A and 2B).

The drying curve was differentiated in terms of the water output speed during the first few minutes of drying between treatments. However, the drying curves of treatments 2-6 and 4-8, of the same origin differed in the presence of fertilization, and the material with fertilization presented a higher initial inclination in the curve, ensuring a faster drying rhythm up to the FSP (Figure 2B).

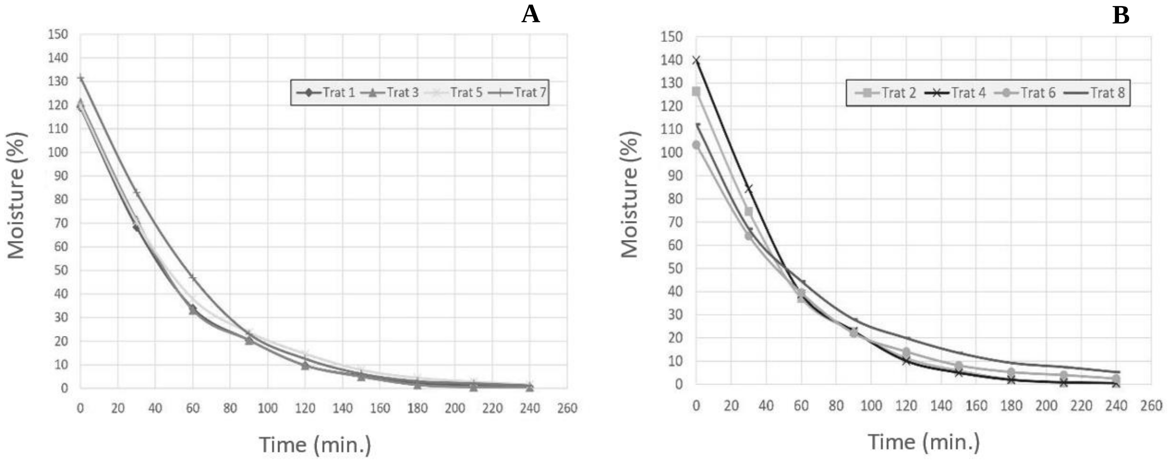

Figure 2. Curves of treatments where fertilization did not interfere with the drying potential (A). Representation of drying curves of treatments where fertilization influenced the drying potential (B).
Figura 2. Curvas dos tratamentos onde a adubação não interferiu no potencial de secagem (A). Representação das curvas de secagem dos tratamentos onde a adubação influenciou no potencial de secagem (B).

The drying rate decreased at each weighing interval for the drying control, and as the moisture content decreased so did the drying rate decrease. Moreover, the drying phases are well-defined in terms of the rates of water output. In the stage where mass transport occurs via capillarity, starting from the initial moisture content to the saturation point of the fibers, which is approximately 30% of moisture, the drying rate is much higher than that found below this point when mass transport is performed via diffusion (Table 4).

The initial inclinations for the drying curves presented in figure 2B were higher for treatments 2 and 4 (with fertilization), indicating a higher initial drying rate, as shown in Table 4. Treatments of the same origin, where fertilization was significantly influenced, presented differences in the initial drying rates.

Table 4. Drying rate for each treatment distributed in the characteristic drying phases.
Tabela 4. Taxa de secagem para cada tratamento distribuído nas fases características da secagem.

	Drying rate (Kg/cm².h.(10^{-3}))		
Treatment	Green wood – 30%	Green wood – 10%	30% - 10%
1	0.373	0.443	0.070
2	0.382	0.459	0.077
3	0.377	0.448	0.071
4	0.399	0.470	0.071
5	0.359	0.431	0.072
6	0.333	0.402	0.069
7	0.391	0.464	0.073
8	0.329	0.402	0.063

The defects were measured during drying, and the results were classified according to the scoring methodology used. The average defect scores obtained from the treatment are shown in Table 5.

Table 5. Score of defects by treatment.
Tabela 5. Escore de defeitos por tratamento.

Treatment	Defect score	
	Rachadura	Collapse
1	Absent	1,84
2	1,25	Absent
3	Absent	1,40
4	1,20	1,15
5	Absent	2,40
6	1,20	1,65
7	1,30	Absent
8	1,10	Absent

The wood density data showed significant differences when subjected to factorial variance analysis, presenting the influence of fertilization, as well as the interaction between fertilization and origin. A significant interaction indicates that dependence between the factors and their unfolding and evaluation is necessary. Thus, the origin within fertilization was evaluated. The unfolding of the interaction origin:fertilization was significant for level A2, which refers to treatments without fertilization. Furthermore, there was a significant interaction for fertilization:origin, in the origins C2 and Se.

The basic density and initial moisture content data showed differences among some of the treatments evaluated. However, according to the statistical analysis used, the other physical properties evaluated did not differ from each other. There was a tendency for treatments with the lowest densities to have higher initial humidity levels (Table 6). These treatments also stood out in terms of drying performance, and a drying curve with a faster decrease was observed, consequently reaching the final moisture content more quickly (Figure 2). The initial moisture content of the wood followed behavior that contrasted with that of the density values. Additionally, the results for the anisotropy coefficient were between 1.67 and 2.06, and the total volumetric contraction of wood was between 8.33% and 9.47% (Table 6).

Table 6. Physical properties of wood.
Tabela 6. Propriedades físicas da madeira.

Treatment	Density (g/cm^3)	Initial moisture content (%)	Anisotropy coefficient	Volume contraction (%)
T1 (C1-C)	0.540 (6.8) ab	119.14 (11.3) ab	1.67 (19.86)	8.34 (12.36)
T5 (C1-S)	0.537 (5.2) ab	119.75 (8.1) ab	1.95 (6.13)	9.47 (10.58)
T2 (C2-C)	0.520 (6.9) ab	126.49 (11.5) ab	2.00 (8.74)	8.33 (9.04)
T6 (C2-S)	0.587 (9.9) a	103.40 (16.9) b	1.97 (13.52)	9.26 (8.09)
T3 (C3-C)	0.530 (5.6) ab	121.23 (19.2) ab	2.06 (16.00)	9.41 (17.52)
T7 (C3-S)	0.506 (3.6) b	131.69 (5.5) ab	1.98 (5.01)	8.50 (5.01)
T4 (S-C)	0.488 (9.6) b	139.95 (16.1) a	2.03 (9.84)	9.07 (8.92)
T8 (S-S)	0.554 (8.8) ab	112.23 (14.3) ab	1.75 (13.39)	9.36 (13.39)

Values in parentheses correspond to the coefficient of variation (%) for the mean values obtained in the treatments. Means followed by the same letter in the column do not differ from each other according to the tukey significant 5% error probability test.

DISCUSSION

From the values of Ti, Tf, and PS, it can be observed that although the temperatures did not differ statistically, they followed the performance of PS, where the treatments that presented the highest PS also presented the highest Ti and Tf. According to Jankowsky (2009), PS is a parameter that emphasizes the ease with which drying can occur during the execution of a program, and is directly associated with its speed. Although Trujillo *et al*. (2021) stated that factors such as air velocity and initial humidity do not affect the drying quality *of T. grandis*, within a program, there is also the relationship between wood moisture and equilibrium moisture (EM). Because the EM is obtained according to the temperature and relative humidity (RH), the drying process takes place depending on these interconnected factors. The higher the temperature and PS, the faster the drying.

Given the results obtained for PS, it is notable that the origin, fertilization, and interaction of origin:fertilization were significant (Table 2). This means that these variables were influenced by the drying program. It was also observed that some treatments differed significantly from the others, and the lowest drying potentials were observed in treatments without fertilization (Table 3). Therefore, the material from areas without fertilization requires a slower drying process to obtain final products with the least number of defects possible when compared with that of the fertilized material. According to Brito *et al.* (1986), fertilization can influence aspects of wood quality. Lima and Gracia (2011) observed the influence of fertilization on the mechanical properties of wood from the species *Eucalyptus grandis.*

The treatments presented drying curves with the standard characteristics for drying wood, where in the first minutes of drying, it was possible to observe the linear trend of the initial phase because of the different levels of water withdrawal ability during the drying process of the wood. In addition to the results obtained by Santos *et al.* (2003), who evaluated the drying curve for *E. grandis* wood, the initial behavior, influenced by the process of mass transport via capillarity, involved in the outflow of free water from the wood. As the moisture content of the wood decreased, the movement flow via capillarity decreased, causing the movement of fluids via diffusion to occur more expressively, which is reflected in the parabolic trend (Figure 2). *Tectona grandis* generally performed well during drying. Braz *et al.* (2015) considered the drying behavior of the species to be good based on its suitability to undergo outdoor drying.

The drying rates in the initial phase showed a notable decrease in treatments with fertilization, which is confirmed by the movement of free water present in the wood without hindrance. This initial phase refers to the predominantly free water outlet, and evaluates the drying rate in the interval between green wood at its initial moisture content until it approaches the FHP, at approximately 30% humidity. These treatments (T2 and T4) were the same as those with lower densities and higher initial moisture contents, which facilitates the understanding of the initial performance of the drying curves (Figure 2B) and the initial rates (Table 4) because it is free water movement. Braz *et al.* (2015) stated that, in general, the movement of free water present in the cellular cavities of the vascular elements of wood occurs easily through evaporation, because free water is held in the wood by capillary forces, losing this type of water occurs more easily, which guarantees higher initial drying rates.

The drying defects generally presented, low rates, with emphasis on treatments of the C1 origin, with and without fertilization, which presented no crack defects. According to Damayanti *et al.* (2020), the permeability of wood is a factor related to drying quality. This species has good permeability, and the core of young teak wood is less permeable than that of sapwood.

The treatments in which fertilization had had a positive effect, showed individuals with larger diameters than those that were not fertilized. Trees of the same origin that received fertilization invested more in radial and vertical growth (Table 1). However, their densities were lower (Table 6). T4 was the only treatment that presented a density that was configured as light wood, whereas the other treatments were classified as medium-density wood types, according to the classification used by Florez *et al.* (2014). The density values obtained in this study are in accordance with those reported in the literature. Dias *et al.* (2018) found a basic density of 0.51 $g \cdot cm^{-3}$ when evaluating individuals at 13 years of age in the state of Minas Gerais. Flórez *et al.* (2014), upon evaluating the basic density in nine *T. grandis* trees, also at 13 years of age, found an average value of 0.53 $g \cdot cm^{-3}$.

Wood density, fertilization, and the interaction of origin:fertilization were significant; therefore, these variables influenced the density of teak wood. Importantly, the areas that were fertilized, regardless of origin, did not differ in terms of the density of the collected material. In contrast, in areas where there was no fertilization, some origins were deferred, revealing clone C2, which had the highest density. The C2 origin without fertilization presented the highest density and the lowest initial humidity among the other genetic materials evaluated (Table 6). It was also among those with the lowest initial Ts (Table 4). Soares *et al.* (2016) found a similar relationship by comparing the drying process of regions of juvenile and adult wood in Eucalyptus species. According to the authors, the samples with the lowest basic density had the highest initial moisture content, and reached the final moisture content more quickly with higher drying rates. Other authors also found this relationship, and wood density, important in predicting the behavior of wood during the drying stage, making it possible to infer that the higher the density, the lower the wood drying rates (BRAZ *et al.*, 2015). Based on the moisture content results, Favalessa *et al.* (2012) stated that the moisture content is inversely proportional to the density of wood, corroborating what was observed in the wood samples of this study.

The anisotropy coefficient, presented inTable 6, classified the wood in most treatments as normal and stable in terms of dimensional variation, which is a factor that favors drying performance characterized by a reduced propensity to develop defects during the process. Only treatments T3 and T4 were above the limit to consider wood as normal according to the classification adopted. According to Logsdon *et al.* (2008), the anisotropy coefficient is the main index for evaluating the dimensional stability of wood. Motta *et al.* (2014) stated that a low anisotropic factor indicates that wood is less prone to warping during dimensional changes caused by dimensional variation during the drying process, consequently, making the wood more stable.

The volumetric contraction (ßv) found in this study is considered to be greater than the data available in the literature for the species (MIRANDA *et al.*, 2011; WANNENG *et al.*, 2014). Volumetric contraction is a factor that represents the stability of wood. The volumetric contraction values found in this study are high when compared with those of the other species; nevertheless, with purposes compatible with those of *T. grandis*, and in competing in rapid growth and potential for applications in high value-added products, the percentage of contraction of *T. grandis* is, in general, lower. This is especially so when considering the volumetric contraction values for African mahogany (*Khaya ivorensis* A. Chev.) ßv =10.60% (REZENDE *et al.*, 2012) and Australian cedar (*Toona ciliata*) ßv =14.73% (BRAZ *et al.*, 2013). Therefore, with the values found for volumetric contraction, *T. grandis* wood still stands out for its dimensional stability.

Because the planting conditions influenced the drying parameters for wood samples of the same species, it is recommended to perform experimental drying to obtain the most appropriate drying parameters for the wood in question, taking into account factors beyond the species. Therefore, it is important to consider the characteristics of the species associated with the planting conditions to which it was subjected to develop the most appropriate program for the material.

CONCLUSIONS

As análises realizadas permitem concluir que:

- The different genetic materials of teak did not influence the initial and final temperatures of the drying program.
- Fertilization is beneficial for drying potential in C1, C2, and SE, with the values of these parameters increasing in fertilized genetic materials.
- The material from fertilized areas presents lower wood density and higher drying rates, which favor faster drying, and consequently, higher drying potentials when compared with individuals who were not fertilized.

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REFERENCES

AMER, M; KABOUCHI, B; RAHOUTI, M; FAMIRI, A; FIDAH, A; ALAMI, S; ZIANI, M. Experimental Study of the Linear Diffusion of Water in Clonal Eucalyptus Wood. **International Journal of Thermophysics**, v41, n142, ago.2020.

BONDUELLE, G.M.; IWAKIRI, S.; TRIANOSKI, R.; PRATA, J.G.; DA ROCHA, V.Y. Análise da massa específica e da retratibilidade da madeira de *Tectona grandis* nos sentidos axial e radial do tronco. **Revista Floresta**, Curitiba, vol. 45, n. 4, p. 671-680, out. / dez.2015.

BRAZ, R. L.; OLIVEIRA, J. T. S.; RODRIGUES, B. P.; ARANTES, M. D. C. Propriedades físicas e mecânicas da madeira de *Toona ciliata* em diferentes idades. **Floresta**, Curitiba, v. 43, n. 4, p. 663 - 670, out. / dez. 2013.

BRAZ, R. L.; DUARTE, A. P. C.; OLIVEIRA, J. T. S.; MOTTA, J. P.; ROSADO, A. M. Curva característica de secagem da madeira de *Tectona grandis* e *Acacia mangium* ao ar livre. **Floresta e Ambiente,** Seropédica, v. 22, n.1, p. 117-123, Jan-Mar 2015.

BRITO, J.O.; FERRAZ, E. S. B.; BARRICHELLO, L.E. G. A adubação mineral e seus efeitos sobre os anéis de crescimento da madeira de Pinus caribaea var. bahamensis. **IPEF**, Piracicaba, v.32, p.5-17, abr.1986.

DAMAYANTI, R., KRISDIANTO, ILIC, J., PARI, G., VINDEN, P. E OZARSKA, B. Wood Permeability Assessment of Young Teak (Tectona grandis L.f.). **Wood Research Journal, Mandsaur** v.11, n.2, oct. 2020.

DIAS, A. C. C.; MARCHESAN, R.; ALMEIDA, V. C.; MONTEIRO, T. C.; MORAES, C. B. Relação entre a densidade básica e as retrações em madeira de teca. **Ciência da Madeira (Brazilian Journal of Wood Science), Pelotas**. V.9, n.1, p. 37-44, mar. 2018.

DURLO, M. A.; MARCHIORI, J. N. C. Tecnologia da madeira: Retratibilidade. Santa Maria: CEPEF/FATEC, 1992, 33p.

FAVALESSA, C. M. C.; UBIALLI, J. A.; CALDEIRA, S. F.; DRESCHER, R.; ACOSTA, F. C. Equações de sortimentos para *Tectona grandis* na região centro-sul de Mato Grosso. **Pesquisa Florestal Brasileira**, Colombo, v. 32, n. 72, p. 389-399, oct /dec. 2012.

FLORÉZ, J. B.; TRUGILHO, P. F.; LIMA, J. T.; HEIN, P. R. G.; SILVA, J. R. M. Caracterización de la madera joven de *Tectona grandis* L.f plantada en Brasil. **Madera y Bosques,** Xalapa, v. 20, n.1 p. 11-20, oct/dec. 2014.

JANKOWSKY, I. **Secagem de madeira equipamento e processos.** Revista da madeira - N°128, ago. 2011.

LIMA, I.L.; GARCIA, J.N. EFEITO DA FERTILIZAÇÃO EM PROPRIEDADES MECÂNICAS DA MADEIRA DE Eucalyptus grandis. **Ciência Florestal**, Santa Maria, v. 21, n. 3, p. 601-608,Jul-Sep. 2011.

LOGSDON, N.B.; FINGER, Z.; BORGES, C.G.A. Caracteri-zação físico-mecânica da madeira de peroba-mica, Aspi-dosperma populifoliumA. DC. (Apocynaceae). **Floresta,** v.38, n.1,jan./mar. 2008.

MEDEIROS, B. L. M. A.; GUIMARÃES JUNIOR, J. B.; RIBEIRO, M. X.; LISBOA, F. J. N.; GUIMARÃES, I. L., T. P. PROTÁSIO. Avaliação das propriedades físicas e químicas da madeira de *Corymbia citriodora e Eucalyptus urophylla x Eucalyptus grandis* cultivadas no Piauí. Nativa, Sinop, v.4, n.6, p.403-407, nov./dez. 2016.

MIRANDA, I.; SOUSA, V.; PEREIRA, H. Wood properties of teak (*Tectona grandis*) from a mature unmanaged stand in East Timor. **Journal of Wood Science**, Tokyo, v. 57, n. 3, p. 171-178, Jun. 2011.

MONTEIRO, T. C.; LIMA, J. T. Water Flow Through the Pits in Eucalyptus urophylla Wood. **Floresta e Ambiente**. V. 27, n. 2, p. e20190092, Jun. 2020.

MOTTA, J. P.; OLIVEIRA, J. T. S.; BRAZ, R. L.; DUARTE, A. P. C.; ALVES, R. C. Caracterização da madeira de quatro espécies florestais. **Ciência Rural**, Santa Maria, v.44 n.12, p.2186-2192, dez. 2014.

NASCIMENTO, T. M.; MONTEIRO, T.C.; BARAUNA, E. E. P.; MOULIN, J. C.; AZEVEDO, A. M. Drying influence on the development of cracks in Eucalyptus logs. **BioResources, Raleigh,** v. 14, n.1, p. 220-233, feb. **2019**.

SANTOS, GRV; JANKOWSKY, IP; ANDRADE, A. CURVA CARACTERÍSTICA DE SECAGEM PARA MADEIRA DE Eucalyptus grandis. **Scientia Forestalis**, Piracicaba,n. 63, p. 214-220, jun.2003.

SOARES, B. C. D.; LIMA, J. T.; SILVA, J. R. M. Analysing the drying behavior of juvenile and mature Eucalyptus saligna wood in drastic drying test for optimal drying schedule. **Maderas-Ciencia y Tecnologia, Concepción** v. 18, n.1, p. 543-554, jun. 2016.

SUSIN, F.; SANTINI, E.J.; STANGERLIN, D.M.; MORAIS, W.W.C.; MELO, R.R. Taxa de Secagem e Qualidade da Madeira Serrada de *Hovenia dulcis* Submetida a Dois Métodos de Secagem. **Floresta e Ambiente**, Seropédica, v.21, n. 2, p. 243-250, jun.2014.

TRUJILLO, F. T.; KLITZKE, R. J.; ROCHA, M. P.; MORA, H. E. G.; SEGURA, C. E. C. THE EFFECT OF AIR VELOCITY ON THE CHARACTERISTICS PRODUCED BY CONVENTIONAL DRYING OF *Tectona grandis* L.f. WOOD. **FLORESTA**, CURITIBA, v. 51, n.4, p. 1019-1028, out/dez 2021.

VIEIRA, C. R.; WEBER, O. L. S.; SCARAMUZZ, J. F. Adubação nos Teores de Cinzas, Carbono e Relação C/N de Teca. **UNICIÊNCIAS**, v. 22, n. 2, p. 124-130, 2018.

WANNENG, P. X.; OZARSKA, B.; DAIAN, M. S. Physical properties of *Tectona grandis* grown in Laos. **Journal of Tropical Forest Science**, Malaysia, v. 26, n. 3, p. 389 –396, 2014.

YANG, L.; LIU, H. A Review of Eucalyptus Wood Collapse and its Control during Drying. **BioResources**, v.13, n.1, p. 2171-2181, feb. 2018