Drying of Eucalyptus Logs from Plantations with Different Spacing between Trees

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The adoption of dense plantations can reduce the drying time of the logs, by optimizing this step. This study evaluated the drying of eucalyptus wood from plantations with different spacing (3 × 4; 3 × 3; 2 × 3; 1 × 3 m). Five trees were selected per treatment. Logs were removed from the base and at 50% and 100% of commercial height for drying evaluation for 60 days. The diameters of the eucalyptus trees from plantations with wider spacing were bigger, and the productivity per hectare was not affected by the spacing between trees. The planting spacing did not affect the initial moisture, which was higher for those removed from the top of the trees. The logs from the base from the denser spacing showed a drying rate 2.5 times higher than the same logs from the treatment with greater spacing, reducing the final moisture from 37.2 to 18.8%. The logs removed from the top of the trees reached the equilibrium moisture after the drying period. The reduction in the planting spacing reduced the wood moisture and the difference in this parameter between the logs removed from the base and top of the eucalyptus trunks.

DOI: 10.15376/biores.18.1.1177-1184

Keywords: Bioenergy; Charcoal; Wood moisture

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INTRODUCTION

The area with forest crops in Brazil is 9.55 million hectares, of which 7.47 million are of the *Eucalyptus* genus with a growing average of 38.8 m³/ha.year (IBÁ - Indústria Brasileira de Árvores 2021). Direct burning or charcoal production for energy generation are among the main uses of this wood (IBÁ 2021). The production chain for bioenergy from wood is extensive and the wood drying is one of the main bottlenecks in this production and, therefore, its optimization is important.

The mass of water can be greater than that of wood in freshly harvested logs (Monteiro *et al*. 2022). Drying in environmental conditions is the most used method to remove this large volume of water, and artificial methods are economically unfeasible in this process (Resende *et al.* 2018). Wood drying for energy generation reduces transport costs (Zanuncio *et al.* 2017; Kozakiewicz *et al.* 2021) and increases the gravimetric yield of carbonization and the charcoal quality (Gebreegziabher *et al.* 2013; Zanuncio *et al.* 2013; Canal *et al.* 2020). Deficiencies in the drying of logs increase the period of this operation, which inhibits the use of wood to produce energy.

Water and wood are connected by different ways, which makes it difficult to predict the drying behavior. Free water connects to wood by capillary bonds, which are easily broken, or by adsorption, which involve stronger bonds. Among these bonds that attach water molecules to the cell wall are hydrogen bonds (Engelund *et al.* 2013). The drying rate is highest at the beginning with the removal of all free water until the fiber saturation moisture (Skaar 1972). After this step, the drying rate is lower due to the higher energy expenditure to remove the adsorption water until the wood reaches equilibrium moisture content, when the difference between sorption and adsorption becomes zero (Oliveira *et al.* 2017).

The choice of plant spacing varies with genetic material, growth, water availability, and final product (Ferraz Filho *et al.* 2018). The diameter of the trees in denser plantations is smaller, reducing the drying time. The greater number of trees per unit of area would compensate for their lower individual volume (André *et al.* 2021) without productivity losses in denser plantations. The adoption of denser eucalyptus plantations produces smaller diameter logs, based on this information, the objective of this work was to evaluate the drying behavior in eucalyptus wood with different planting spacings.

EXPERIMENTAL

Biological Material

Five six-year-old trees of a *Eucalyptus urophylla* clone were selected per treatment in plantations with similar characteristics of climate and soil and spacing of 1 × 1; 2 × 3; 3 × 3 and 3 × 4 m per tree, for a total of 20 trees. The volume of wood per hectare and treatment was provided by the producer based on inventory data. The material was collected in the municipality of Três Marias, Minas Gerais state, Brazil (18° 12' 21" S 45° 14' 31" W and average altitude of 527 m) with a climate, according to the Köppen classification, characterized by humid summers and dry winters with average annual temperature and precipitation of 19.8 to 25.3 °C and 1,200 to 1,500 mm, respectively (Alvares *et al.* 2013).

Wood Drying

Eucalyptus trees were harvested, and logs were removed at 1.1 meters from the base and at 50 and 100% of commercial height (up to 4 cm in diameter), trunk diameters were measured with a tape measure. A 5 cm disk was removed from the ends of each log to determine its moisture in a dry basis, according to Eq. 1, therefore, the logs subjected to drying were 1 meter long.

$$M_{db} = ((M_w - M_d)/ M_w) \times 100 \quad (1)$$

where M_{db} *is* moisture on a dry basis (%), M_w is wet mass of the material and M_d is dry mass of the material.

The average moisture of the discs, removed from each log, was considered as the initial moisture of the log (Fig. 1).

The wood drying took place in the municipality of Viçosa, Minas Gerais state, Brazil (20° 45′ 17″ S, 42° 52′ 57″ W), with an average annual temperature and precipitation of 19 °C and 1,314.2 mm. The eucalyptus logs were conditioned parallel to the ground, in a covered place with free air passage and without contact with each other to evaluate the wood air-drying for 60 days. Moisture loss is more pronounced in the first days and, therefore, these logs were weighed daily during the first 20 days and, after this period, on alternate days until the end of drying. The drying rate was calculated as follows,

$$D_r = M_l / t \tag{2}$$

where *Dr* is drying rate (%/day), *Ml* is moisture loss based on dry mass (%), and *t* is the period of drying (days). A wood moisture curve, as a function of days during the drying period, was generated for the eucalyptus logs per planting spacing and axial position.

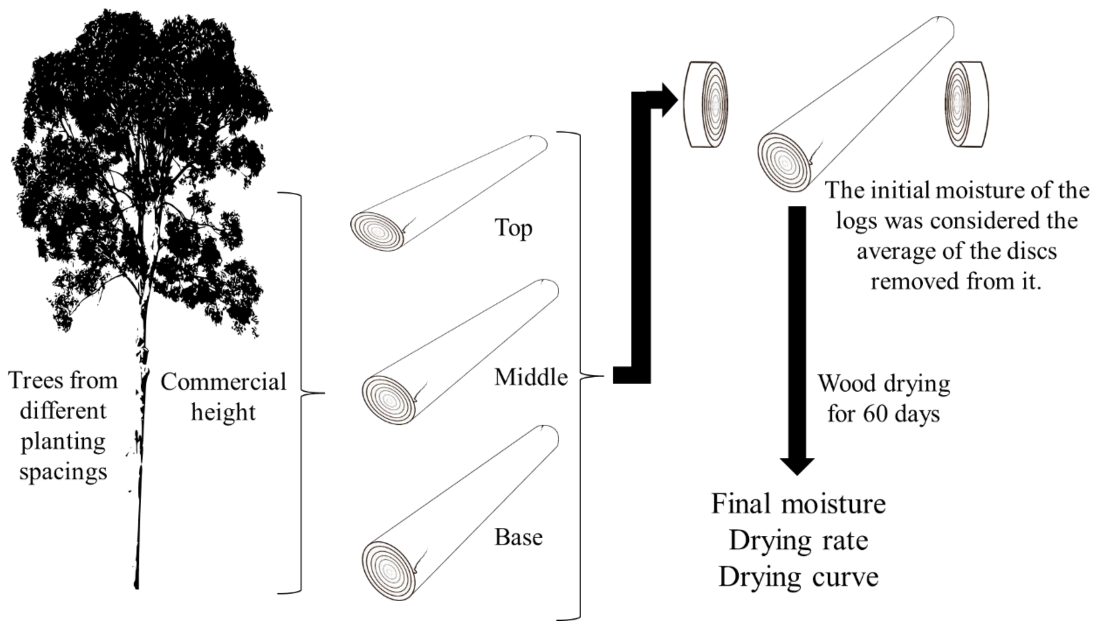

Fig. 1. Removal of samples from eucalyptus trunks to evaluate wood drying.

RESULTS AND DISCUSSION

The commercial height of eucalyptus trees ranged from 15.3 to 21.1 m. The diameter of the logs ranged from 8.08 to 15.56 cm; 6.20 and 10.63 cm and 3.46 to 4.39 cm at the base, middle and top, respectively. The wood volume per hectare varied between 137 and 145 m³/ha (Table 1).

Table 1. Diameter (cm) at the Base (DB), Middle (DM) and Top (DT), Height (Hei.) and Productivity (Prod.) of Eucalyptus Trees in Plantations with Different Spacing

Spacing	DB (cm)	DM (cm)	DT (cm)	Height (m)	Prod. (m^3/ha)
A (3x4 m)	$14.5^{3.4}$	$9.79^{3.7}$	$4.06^{2.3}$	$18.3^{5.3}$	137
B (3x3 m)	$14.06^{4.1}$	$9.54^{3.2}$	$3.89^{2.8}$	$18.4^{5.9}$	133
C (2x3 m)	$13.52^{3.3}$	$8.65^{3.8}$	$3.92^{2.5}$	$19.6^{6.3}$	141
D (1x1 m)	$10.18^{3.8}$	$7.08^{3.0}$	$3.99^{2.7}$	$21.1^{6.1}$	145
*Values in superscript represent the coefficient of variation					

The dimensions of the trees varied with the planting spacing. Reducing the space between trees in forest plantations decreased the diameter in 42 and 38% for the logs removed from the base and 50% of the commercial height, with greater reduction between the spacing C (2 × 3 m) and D (1×1 m). The diameter of the logs from the top did not vary between spacing as they correspond to the commercial height, 4 cm in diameter in eucalyptus trees. Plant height in denser plantations (D 1x1) was 13% higher than in A (3x4). The lower tree diameters in the densest plantations are due to the higher competition, making it difficult for a tree to grow. The wood volume per hectare varied from 133 to 145 m^3/ha with the greater number of trees per hectare in the denser plantations compensating the lower productivity per plant, making the volume per hectare near between spacing.

The initial log moisture was greater at the top, followed by the middle and bottom in all planting spacing. The drying rate of logs from the top of denser plantations was higher, resulting in lower moisture after the drying period (Table 2).

Table 2. Initial Moisture (%), Drying Rate (%/day) and Final Moisture (%) of Logs from the Base, Middle and Top of Eucalyptus Trees from Plantations with Different Spacing and Dried for 60 days

Parameter	Spacing	Base	Middle	Top
Initial moisture (%)	A (3 × 4 m)	93.4 $^{5.9}$Aa	100.3 $^{6.8}$ Aa	134.2 $^{7.3}$ B
	B (3 × 3 m)	82.6$^{8.1}$Ab	102.9$^{7.3}$ Ba	128 ,6 $^{7.2}$C
	C (2 × 3 m)	73.1$^{5.1}$ Ac	97.1$^{5.4}$ Ba	143.7 $^{6.8}$ C
	D (1 × 1 m)	90.5$^{4.9}$ Aa	109.3$^{7.7}$ Ba	125.8$^{7.8}$ C
Drying rate (%/dia)	A (3 × 4 m)	0.38$^{6.8}$Aa	0.66$^{7.3}$ Ba	1.20$^{8.9}$ Ca
	B (3 × 3 m)	0.70$^{7.5}$ Ab	1.18$^{7.4}$Bb	1.63$^{7.4}$Cb
	C (2 × 3 m)	0.69$^{8.2}$Ab	1.15 $^{8.5}$Bb	1.81$^{8.4}$Cc
	D (1 × 1 m)	1.04$^{6.5}$ Ac	1.33$^{9.1}$Bc	1.81$^{6.9}$Cc
Final moisture (%)	A (3 × 4 m)	37.2$^{4.3}$Aa	20.9$^{3.6}$ Ba	15.2$^{4.2}$ Ca
	B (3 × 3 m)	30.5$^{4.1}$ Aa	19.6$^{3.8}$ Ba	15.4$^{3.8}$ Ca
	C (2 × 3 m)	23.3$^{3.2}$Ab	17.5$^{3.5}$Bb	15.5 $^{3.5}$ Ba
	D (1 × 1 m)	18.8^{34} Ac	17.3$^{3.7}$Ab	15.3$^{3.3}$ Ba

Means with capital letters horizontally or lowercase letters vertically, per parameter, do not differ by the Scott-Knott test at 5% significance. Superscripted values represent the coefficient of variation.

The moisture of the logs from the top was higher. The quantity of water in the wood is related to the wood formation and maturation processes and the incipient cambial activity in the wood from top reduces its density and increases its void volume filled by free water (Zanuncio *et al*. 2013). In addition, the wood from this region is composed only of sapwood, without tyloses and, therefore, with higher water content (Mishra *et al*. 2018; Jevšenak *et al*. 2019).

The drying rate was higher and the final moisture lower in the smaller diameter wood logs. Variations in the diameter between the bottom and top of the logs were greater for plants under 3 × 4 planting spacing, with a difference from 0.38 to 1.2%/day in the drying rate and from 37.2 to 15.2 % in the final moisture. The drying rate and the final moisture content of logs removed from the base in the treatments with planting spacing of 3 × 4 and 1 × 3 m increased by 0.38 to 1.04%/day and decreased by 37.2 to 18.8%, respectively. The path for water to travel from inside the wood to the surface and evaporate is lower in shorter diameter logs, accelerating the drying rate and reducing the final moisture content of the logs (Engelund *et al*. 2013; Zanuncio *et al*. 2015). Moisture at the end of drying period in the logs from the base region decreased by 19% between the 3 × 4 and 1 × 3 spacings, reducing fuel consumption per ton of dry wood transported and the fleet needed for its transport it (Zanuncio *et al*. 2017). In addition, this increases the wood calorific value, carbonization yield, and charcoal quality (Zanuncio *et al*. 2013; Canal *et al*. 2020) without losses in dry matter through biodeterioration (Civitarese *et al*. 2015).

The wood moisture losses was faster at the beginning of the drying process, especially for logs with smaller diameters (Fig. 2).

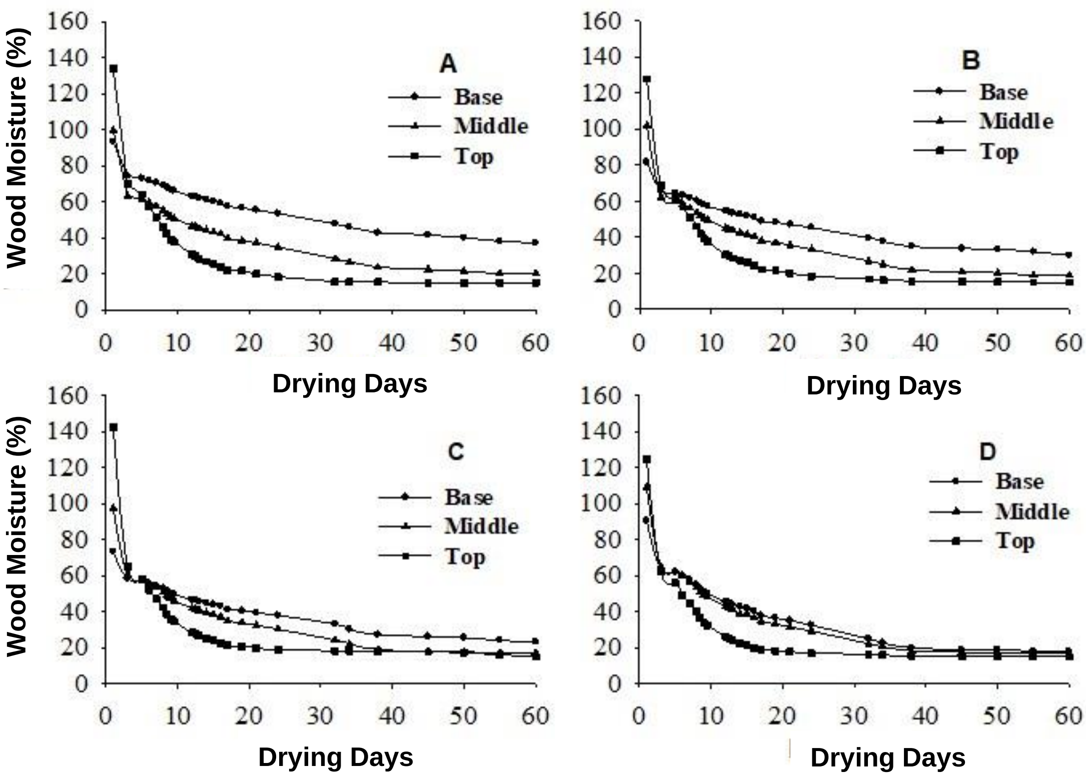

Fig. 2. Wood Moisture (%) and drying days of logs taken from the base, middle and top of eucalyptus trees in plantations with different spacing (A= 3 × 4 m; B= 3 × 3 m; C= 2 × 3 m and D= 1 × 1 m)

The wood drying rate of logs was higher at the beginning of the drying period, regardless of planting spacing and axial log position. The first days of drying are marked by the free water losses, connected to the wood by weak capillaries; therefore, the loss of moisture is greater at the beginning of the drying process (Yang and Liu 2018). The moisture gradient of the wood and the environment decreases until the fiber saturation point (approximately 30% moisture) and, below this level, a greater energy expenditure is required to remove the absorption water due to its hydrogen bonds with the cell wall, reducing the drying rate (França *et al*. 2019). The reduction in planting spacing also reduced the difference in moisture content between logs from different axial positions in the densest spacing (1×1 m), the logs at the base, middle and top showed 18.8, 17.3 and 15.3% moisture, respectively, at the end of the drying period. The reduction of planting spacing is a viable technique for forest plantations aiming to produce energy by reducing the final moisture content of the logs and the difference in this parameter between those removed from different axial positions of the tree.

CONCLUSIONS

1. The initial wood moisture content did not vary with planting spacing, but value of this parameter was higher for logs removed from the tops of trees.
2. The drying rate in the logs from the planting spacings of 3 × 4 and 1 × 3 m was 0.38 and 1.04%/day, respectively, reducing the final moisture content from 37.2 to 18.8 % after the drying period.
3. Differences between the moisture of the base and top in the logs from denser plantations were smaller, resulting in more homogeneous material.
4. The use of denser plantations is effective to obtain materials with lower moisture and less variation between logs removed from the base and top of the trunks after the drying period. This technique is viable for eucalyptus plantations intended for the wood production to generate energy.

ACKNOWLEDGMENTS

This work was supported by the Brazilian agencies “Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)”; “Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)”, “Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG- APQ-03512-18) and by the Portuguese agency “Fundação para a Ciência e a Tecnologia (FCT)” through funding of the Forest Research Centre (Grant No. UID/AGR/00239/2019 and Grant No. UIDB/00239/2020) and CLEANPELL (Grant No. EXPL/CTM-PAM/0850/2021). Solange Araújo acknowledges funding from the FCT for their research contracts (DL 57/2016/CP1382/CT0018).

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Article submitted: October 24, 2022; Peer review completed: November 20, 2022; Revised version received and accepted: November 27, 2022; Published: December 19, 2022.
DOI: 10.15376/biores.18.1.1177-1184