PREDICTING MOISTURE CONTENT FROM BASIC DENSITY AND DIAMETER DURING AIR DRYING OF EUCALYPTUS AND CORYMBIA LOGS

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ABSTRACT

In air drying of *Eucalyptus urophylla* and *Corymbia citriodora* logs for the production of charcoal it is necessary to be able to predict when logs have reached the required moisture content of $\leq 35\%$. This study is aimed to produce models using basic density and diameter to predict the moisture content of *Eucalyptus urophylla* and *Corymbia citriodora* logs after 30, 60 and 90 days drying. 1,2 m long logs were taken at three different heights from three *C. citriodora* trees and three trees each from two *E. urophylla* clones (VM4 and Mn463). The 27 debarked, end sealed logs were air dried under cover for 90 days during which the change in moisture content was monitored. The relationship between density and drying was analyzed by Pearson's correlation coefficient and the models for predicting the moisture content based on the basic density and diameter were produced. The density and the drying showed a high correlation coefficient. The coefficient of determination of the models was above 0,89 with a standard error lower than 6%. The use of the density and diameter to estimate the wood moisture content simplifies the production of the models, which can be used for *Eucalyptus* and *Corymbia* genetic materials.

Keywords: Biomass, drying, wood.

INTRODUCTION

The world seeks to reduce the burning of fossil fuels to reduce the greenhouse effect (Zhu *et al.* 2011), and biomass use is a viable alternative (Protásio *et al.* 2013, Musinguzi *et al.* 2012, Telmo and Lousada 2011).

The charcoal produced from cultivated *Eucalyptus* spp. is mainly used in the steel production in Brazil. The consumption of eucalyptus logs reached nearly 17 million/m³ in 2011 (Associação Brasileirade Produtores de Florestas Plantadas – ABRAF, 2012), which demands wood with ≤35% moisture content for charcoal production (Brand *et al.* 2011).

The drying of wood has been studied for over a century (Engelund *et al.* 2013), but there are few studies on logs. The air-drying method is the most common one to reduce the log moisture content. A reduction of 10% in the moisture content increases the calorific value by 2 MJ/kg (Swithenbank *et al.* 2011). However, in the field, the logs are not dried until the equilibrium moisture content level, because the increase in calorific value is not worth the effort to keep drying after reaching a certain moisture content.

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The drying of wood is not homogeneous with higher rates in the early days because of the removal of free water, and this rate decreases until equilibrium moisture content is reached. Environmental factors such as relative humidity, temperature, and wind speed as well as wood factors such as anatomy, density, and diameter of the logs affect the drying process (Larsen and Ormarsson 2013, Mugabi *et al.* 2010, Rémond *et al.* 2013, Rezende *et al.* 2010).

The characteristics such as the diameter and density may allow the use of one type of model to predict moisture content for different genetic material (Zanuncio *et al.* 2013) . The aim of this study was to evaluate the relationship between wood basic density and diameter with drying of wood and establish models for predicting the moisture content of *Eucalyptus urophylla* and *Corymbia citriodora* logs after 30, 60, and 90 days of drying.

MATERIAL AND METHODS

Three *C. citriodora* trees produced from seeds, three from the clone VM4 (*E. urophylla*) and three from the clone Mn463 (*E. urophylla*) were used, totaling nine trees. Logs with 1,2 m length were cut and debarked from the base, at 50%, and at 100% of the commercial height of the trees for the drying process, totaling 27 log cuts (Figure 1).
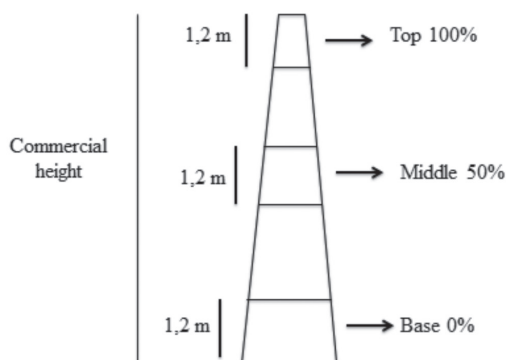
Figure 1. Sampling scheme of logs to evaluate drying.

The *C. citriodora* and *E. urophylla* logs had their transverse surfaces waterproofed and placed in a covered area without touching each other. In the first 20 days, the logs were weighed every two days, every four days in the next 30 days and every seven in the next 40 days, totaling 90 days of drying.

A disc of 10 cm was removed from each pole of the logs after cutting the trees. The moisture content of the disk was determined from the ratio of the water mass and wood dry mass, and basic density was determined from the ratio of the wood dry mass and the wood green volume, according to NBR11941/2003 (Associação Brasileirade Normas Técnicas–ABNT, 2003). The average value of these parameters was considered as the moisture content and basic density of the logs.

The drying rate was calculated with the formula:

$$Ts = \left(\frac{PU}{D} \right)$$

(1)

where, Ts= drying rate (%/day), PU= loss of moisture content based on dry mass (%), and D= drying period (days).

The relationship between basic density and the initial moisture content, drying rate, and the final moisture content of the logs in their respective diameter classes was obtained with the Pearson's correlation coefficient.

The moisture content of the logs after 30, 60, and 90 days of drying was estimated with the model:

$$U = exp^{(b_0 + b_1 * Den + b_2 * Dia)}$$

(2)

where U= Moisture content of the logs after 30, 60, and 90 days of drying; Den= basic density of the logs; Dia= diameter of the logs; b_0, b_1, and b_2= regression parameters. This model was based on the drying behavior of *Eucalyptus* logs (Rezende *et al.* 2010).

The equation was evaluated by coefficient of determination and the standard error of the estimates. Furthermore, a graphic analysis of residues was performed in software SigmaPlot 11.0 to verify the existence of trends.

RESULTS AND DISCUSSION

The *C. citriodora* logs showed higher density and lower initial moisture content in the respective diameter classes, with a reverse trend as compared to the Mn463 (*E. urophylla*) (Table 1). The basic density of *E. urophylla* clones was similar for the species of this genus, 0,482 to 0,648 g/cm³, as reported for *Eucalyptus benthamii, Eucalyptus camaldulensis; Eucalyptus grandis, Eucalyptus nitens* and *Eucalyptus urophylla* (Couto *et al.* 2013 Inagaki *et al.* 2012, Martins *et al.* 2013, Medhurst *et al.* 2012).

Table 1. Basic density, diameter and initial moisture content of the *Corymbia citriodora* and *Eucalyptus urophylla* logs.

| Material	Average height (m)	Position	Basic Density (kg/m³)	Diameter (cm)	Initial moisture content (%)
Corymbia citriodora	22,65	Base	665	17,9	78,47
		Middle	684	12,6	75,43
		Top	674	4,3	74,39
Mn 463 (*Eucalyptus urophylla*)	30,45	Base	508	20,3	121,52
		Middle	510	14,2	112,59
		Top	511	4,6	126,15
VM 4 (*Eucalyptus urophylla)*	29,45	Base	529	19,4	94,54
		Middle	579	13,3	84,52
		Top	567	4,7	80,99

The genetic materials of *C. citriodora* and the VM4 (*E. urophylla*) had higher initial moisture content at the base, while those of Mn463 (*E. urophylla*) were higher at the top. The amount and distribution pattern of moisture content in the longitudinal direction may vary according to the genetic material, as reported for *C. citriodora, E. cloeziana, E. grandis, E. paniculata, E. pilularis, E. tereticornis* and *E. urophylla* (Engelund *et al.* 2013, Oliveira *et al.* 2005).

The drying rate of all materials was higher in the first 20 days (Figure 2) what was similar to that reported for *Cryptomeria japonica* lumber and *Betula papyrifera* flakes (Bedane *et al.* 2011, Hermawan *et al.* 2012). This can be explained by the loss of the free water, which is easily removed due to weak capillary connections with the wood (Skaar 1972). However, this rate decreases until the timber reaches the equilibrium moisture content (Rezende *et al.* 2010).

The logs from the top had the highest drying rates: 0.637; 1.224 and 0.724 %/day for *C. citriodora*, Mn463 (*E. urophylla*), and VM4 (*E. urophylla*), respectively, particularly during the first 30 days (Figure 2). End sealing normally decreases drying rate because of transverse surfaces lose moisture faster than other surfaces. Logs with smaller diameter had larger surface/volume ratio, resulting in higher drying rate and lower moisture content after 90 days drying. All these logs reached moisture content below 35%, which is recommended for carbonization.

The drying rate of logs from the middle of *C. citriodora*, Mn463 (*E. urophylla*), and VM4 (*E. urophylla*) were 0.611; 0.883 and 0.592%/day, respectively. All these logs reached the final moisture content lower than 35%, as required for carbonization, with shorter period for *C. citriodora* (Figure 2).

The larger diameter increase the distance traveled by the water inside the wood and reduced its drying rate. The drying rate of *C. citriodora,* Mn463 (*E. urophylla*), and VM4 (*E. urophylla*) was 0.526, 0.669, and 0.601%/day, respectively (Figure 2). Although with lower drying rate, the lower initial moisture content favored *C. citriodora* logs and only those of the base for this material reached the 35% moisture content after 90 days of drying, necessary for charcoal production. The reduction in moisture content increases the net calorific value and carbonization yield of the logs (Arruda *et al.* 2011).
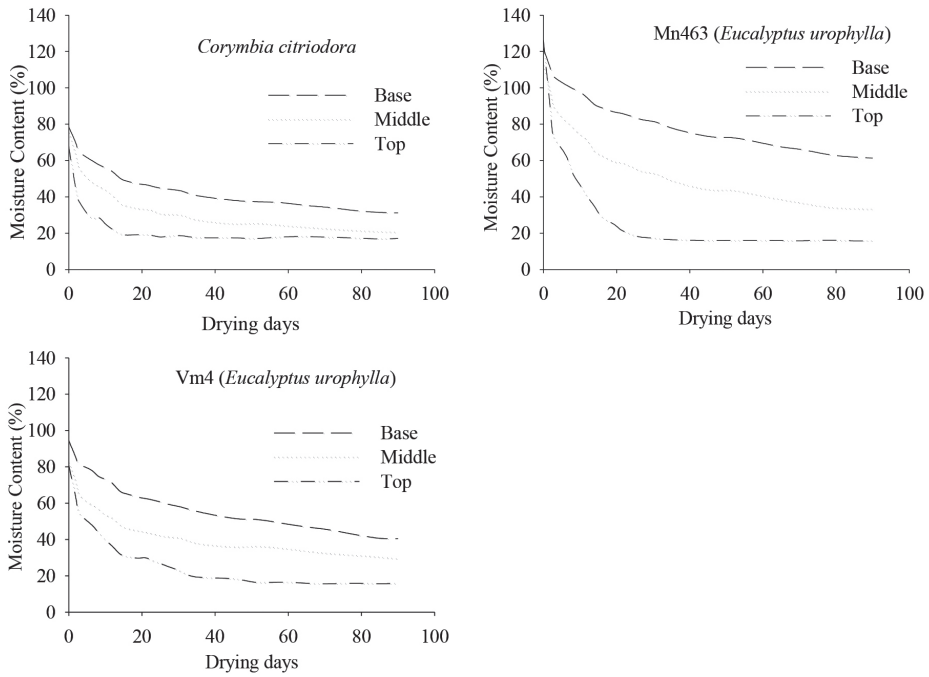
Figure 2. Changes in moisture content of *Eucalyptus* and *Corymbia* logs after 90 days of drying.

The density of the timber was inversely proportional to the initial moisture content, drying rate and final moisture content for the base, middle and top materials, except for the relationship between the density and final moisture content of the logs from the top (Table 2).

Table 2. Pearson's correlation coefficient between the basic density of the base, middle and top logs with their initial moisture content, drying rate and final moisture content after 90 days of drying.

Position	Correlation coefficient		
	Initial moisture content of logs from base	Drying rate of logs from base	Final moisture content of logs from base
Basic density from base	-0,882	-0,861	-0,831
	Initial moisture content of logs from middle	Drying rate of logs from middle	Final moisture content of logs from middle
Basic density from middle	-0,886	-0,765	-0,888
	Initial moisture content of logs from top	Drying rate of logs from top	Final moisture content of logs from top
Basic density from top	-0,869	-0,879	0,255

The basic density showed relationship with the drying, with a correlation coefficient ranging from −0.888 to 0.255. The wood with lower density has many spaces to be filled by free water, resulting in higher wood moisture content (Skaar 1972). These empty spaces facilitate the flow of water and increase the drying rate, but this was not sufficient to offset the higher initial moisture content of the logs. Therefore, wood with the highest density showed lower moisture content after 90 days of drying, which is similar to that observed for *Cryptomeria japonica*, *Eucalyptus grandis* and *Tsuga heterophylla* lumber (Berberovic and Milota 2011, Mugabi et al. 2010, Watanabe et al. 2012).

Considering the coefficient of correlation between the density and moisture content of the logs from the top. The smaller diameter reduces the distance traveled by the water inside the wood and facilitates the drying of the logs and these reached equilibrium moisture content after 90 days of drying.

Regression models for the moisture content prediction after 30, 60 and 90 days drying showed high correlation coefficient and low standard deviation (Table 3).

Table 3. Regression models for wood moisture content after 30, 60 and 90 days of drying based on basic density and diameter of the *Eucalyptus* and *Corymbia* logs.

Drying Time (Days)	Estimated model for moisture content after 30,60 and 90 days drying	R^2	$S_{y,x}$
30	$U = \exp^{(3,97683 - 2,26202*d + 0,07328*di)}$	0,926	5,18
60	$U = \exp^{(3,75761 - 2,21927*d + 0,07514*di)}$	0,921	5,14
90	$U = \exp^{(3,73064 - 2,31586*d + 0,07050*di)}$	0,892	5,92

d= basic density (g/cm^3); di= diameter (cm); R^2= Coefficient of determination; $S_{y,x}$ = Standard error (%)

The accuracy of the models reflects the high correlation coefficient between the wood basic density and moisture content. The relationship between the moisture content, basic density and diameter showed an exponential curve. Increasing the diameter reduces the surface/volume ratio exponentially, as evidenced by the curve of moisture content for 30, 60, and 90 days of drying (Figure 3). Higher density reduces the empty spaces inside the wood and decreases the initial moisture content of the logs, which occurred throughout the drying period for logs with larger diameter. The residue distribution was homogeneous for the three models, showing heteroscedasticity with an upward trend for higher moisture content due to data variability. Other factors inherent of the wood, as the percentage of sapwood also influence the wood drying and may have contributed with the difference between values sampled and the values estimated.
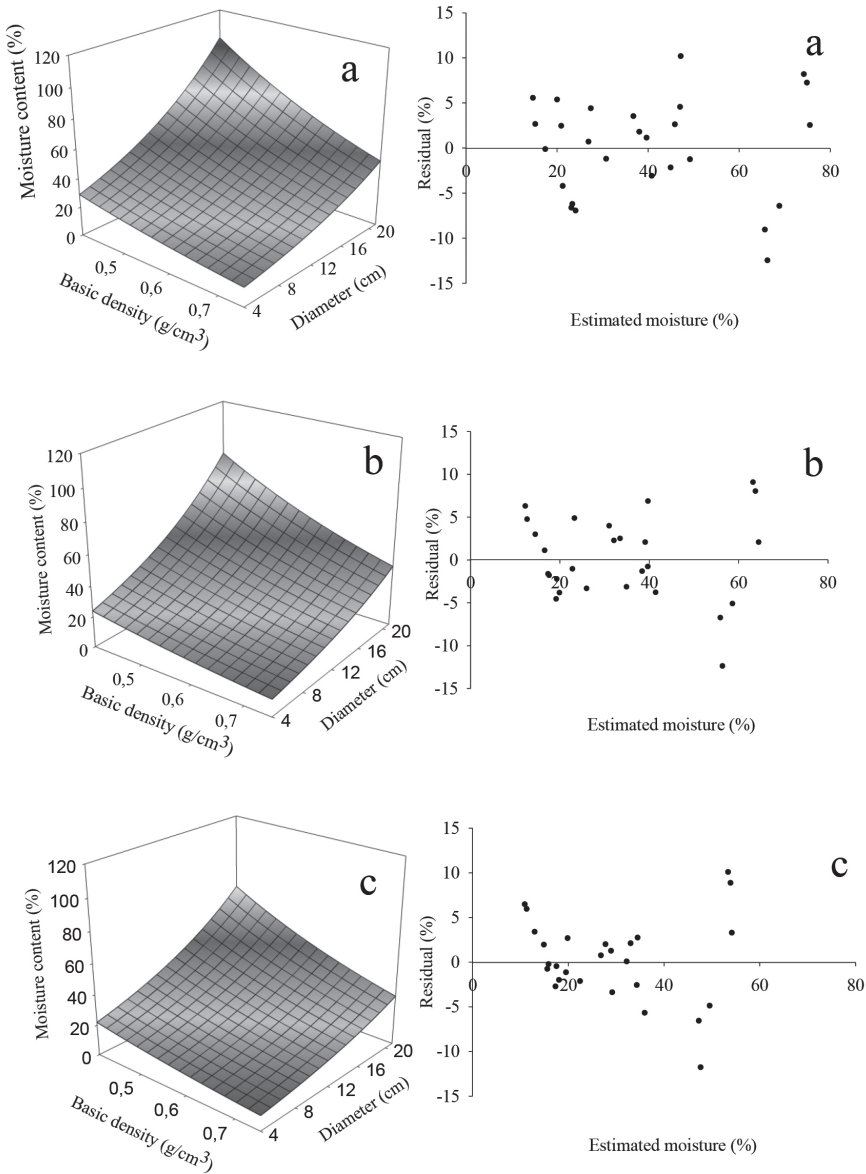
Figure 3. Relationship between moisture content, basic density and diameter with 30 (a), 60 (b) and 90 (c) days of drying.

The moisture content of wood can be predicted from the basic density and diameter of *C. citriodora* and *E. urophylla* logs for specific periods. This method can facilitate field operations and reduce costs because the same model can be used for various genetic materials. The models can predict the variability in the moisture content of the wood, but they must be adapted to each climatic condition, because factors such as the temperature and relative humidity also influence the drying (Gebreegziabher *et al.* 2013, Korkut *et al.* 2013). Therefore, future studies should also consider the environmental variables to increase the application of these models in the field.

CONCLUSIONS

Corymbia citriodora had the lowest moisture content in all periods, while the clone Mn463 (*E. urophylla*) showed higher values. The high correlation coefficient between density and moisture content allowed the production of models relating to these variables. The models based on the basic density and diameter can be used to estimate the moisture content in *C. citriodora* and *E. urophylla* logs after 30, 60, and 90 days of drying. The wood from genetic materials with higher density showed lower moisture content after the drying period.

ACKNOWLEDGEMENTS

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