ISSN 0104-7760

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# IMPORTANCE OF WOOD DRYING TO THE FOREST TRANSPORT AND PULP MILL SUPPLY

Keywords:
Cellulosic pulp
*Corymbia*
*Eucalyptus*
Logs
Moisture

**ABSTRACT:** The forest transportation represents a great proportion of raw material cost for pulp and paper production and, for this reason, the wood moisture content should be low to reduce these cost. The objective was to relate the wood moisture with fuel consumption per kilometer in each vehicle and the number of trips to supply a pulp mill. Three trees of *Eucalyptus urophylla* clone and three of *Corymbia citriodora* from seeds were used. These trees were felled and their logs removed from its base and at 50 and 100% of the commercial height. The basic density and initial moisture of wood were determined and the air drying monitored during 90 days. The fuel consumption to transport one ton of dry wood and the number of trips required to supply a pulp mill were estimated based on the number of air drying days. Air drying reduced the fuel consumption and the number of trips to supply the pulp mill. The accuracy of models to estimate the wood moisture, fuel consumption and the number of trips based in days of drying was high. Therefore, wood drying is an essential tool to reduce forest transport costs.

Histórico:
Recebido 23/08/2016
Aceito 24/03/2017

# IMPORTÂNCIA DA SECAGEM DA MADEIRA PARA O TRANSPORTE FORESTAL E ABASTECIMENTO DE FÁBRICAS DE POLPA CELULÓSICA

Palavras chave:
*Corymbia*
*Eucalipto*
Polpa celulósica
Umidade
Toras

**RESUMO:** O transporte florestal representa uma grande proporção do custo da matéria-prima para a produção de papel e celulose, por esse motivo, o teor de umidade da madeira deve ser baixo para reduzir esses custos. O objetivo deste trabalho foi relacionar a umidade da madeira com o consumo de combustível por quilômetro em cada veículo e o número de viagens necessárias para abastecer uma fábrica de celulose. Três árvores de um clone de *Eucalyptus urophylla* e de *Corymbia citriodora* com produção seminal foram utilizadas. As árvores foram abatidas e seus troncos foram removidos de sua base e 50% e 100% da altura comercial. A densidade básica e a umidade inicial da madeira foram determinadas e a secagem ao ar foi monitorada durante 90 dias. O consumo de combustível para transportar uma tonelada de madeira seca e o número de viagens necessárias para abastecer uma fábrica de celulose foram estimados com base no número de dias de secagem. A secagem ao ar livre reduziu o consumo de combustível e o número de viagens para abastecer a fábrica de celulose. A precisão dos modelos para estimar a umidade da madeira, o consumo de combustível e o número de viagens com base nos dias de secagem apresentaram alta precisão. Portanto, a secagem de madeira é uma ferramenta essencial para reduzir os custos do transporte florestal.

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DOI:
10.1590/01047760201723022223

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## INTRODUCTION

All freshly cut timber has high quantities of water when harvested (KOLLMANN; CÔTÉ, 1968; BRAND et al., 2011; TAHVANAINEN et al., 2014), requiring drying before transporting this material (ZHU et al., 2011). The outdoor storage is commonly used to reduce logs moisture (BRAND et al., 2010; ZANUNCIO et al., 2015). This method is the most used in wood for pulp production, with low cost, but requires long drying period.

The drying rate over time is heterogeneous due to different relations between water and wood (REZENDE et al., 2010; KORKUT et al., 2013), which complicates its control. The water in the vessel elements, lumen and others void spaces are connected to the wood by weak capillary connections, forming the free water (SKAAR, 1988). The water retained in the cell wall by hydrogen bonds is called adsorption water; its removal is slow and requires more energy due to the strength of its connection to the wood (ENGELUND et al., 2013). Finally, the water of constitution can be removed only after the complete wood degradation (SKAAR, 1988).

The forest transport is one of the highest wood costs (MACHADO; LOPES, 2000; ALVES et al., 2013). The vehicles for such transport have loading capacity by mass. Therefore, transporting wood with high moisture increases costs of this operation (TAHVANAINEN; ANTTILA, 2011). This is due to the large amount of water in the timber, in addition to increasing the number of trips to meet the pulp mill demand.

The objective of this study was to evaluate the drying of logs and relate the *Corymbia citriodora* and *Eucalyptus urophylla* wood moisture with fuel consumption in each vehicle and number of trips required to supply a pulp mill.

## MATERIAL AND METHODS

Three seven-years-old trees of *Eucalyptus urophylla* clone and three of *Corymbia citriodora* from seeds were collected in Paraopeba, Minas Gerais state, Brazil, (19° 16' 26" S 44° 24' 14" W). These trees were cut and 1.1 meters logs were removed at the base and at 50 and 100% of the commercial height,which represents the height until the tree reach diameter of 4 cm (Table 1). A 5 cm thick disc was removed from the ends of each log to determine the initial moisture and basic density of the logs. Moisture of these discs was determined by the ratio between the water mass and the wood dry mass. The basic density was determined by the ratio between dry mass and wood green volume, according to NBR 7190 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - 1997). Moisture and basic density of logs were obtained with the weighted average of the discs.

**TABLE 1** Diameter of *Corymbia citriodora* and *Eucalyptus urophylla* logs along the longitudinal direction

| Material | Position | Diameter (cm) | Commercial height (m) |
|---|---|---|---|
| *Corymbia citriodora* | Base | $17.88^{8.1}$ | $22.65^{7.3}$ |
| | Middle | $12.56^{9.5}$ | |
| | Top | $4.3^{3.2}$ | |
| *Eucalyptus urophylla* | Base | $19.45^{5.1}$ | $29.45^{9.3}$ |
| | Middle | $13.34^{4.0}$ | |
| | Top | $4.7^{2.6}$ | |

Values in superscript represent the coefficient of variation.

The ends of each log were water proofed to prevent drying in the transverse direction and better simulate field condition. Then, the logs were placed in a covered area and arranged at approximately 15 cm from each other. They were weighed every alternated day during the first 20 days and every four and seven days interval in the next 30 and 40 days, with a total of 90 days of drying. Moisture losses curve versus time was prepared for each material.

Fuel consumption for wood transport has been calculated considering an average consumption of two liters of diesel per kilometer in vehicle capable of carry 31.2 tons of wood (Equation 1). A curve of fuel consumption per ton of dry wood transported as function of days of drying was prepared**.** Where: Cm= fuel consumption per ton of dry wood transported per kilometer; Ckm= fuel consumption per kilometer run, 2-liter diesel; Cc= capacity of wood transport vehicles, 31.2 tons per trip; U= wood moisture on dry basis.

$$Cm = \frac{Ckm \times (1+u)}{Cc} \quad [1]$$

The number of daily trips needed to supply a pulp mill considered a production of 1.5 million tons per year, which requires 3 million tons of wood, considering a pulping yield of 50% (SEVERO et al., 2013). The plant operates 355 days per year and, therefore, it takes approximately 8450 tons of wood per day (Equation 2). A curve of the number of trips based on days of drying was prepared considering a 31.2 tons load capacity per trip (Equation 2). Where: Nv= number of trips to supply the pulp mill; Dd= daily demand of dry wood in a pulp mill, 8,450 tons of wood; Cc= capacity of wood transport vehicles, 31.2 tons per trip; U= moisture content of wood in dry basis.

$$Nv = \frac{Dd \times (1+U)}{Cc} \quad [2]$$

The model [3], based in the log drying behavior (REZENDE et al., 2010; ZANUNCIO et al., 2013), was used to estimate moisture, fuel consumption and the number of trips as a function of days of drying (Equation 3). Where: Y= moisture (%) or fuel consumption per ton of wood transported ($L\cdot T^{-1}$) or number of trips to supply the pulp mill; a, b, c= equation parameters; d= days drying.

$$Y=a+b\cdot d+c\cdot d^{0.5} \qquad [3]$$

## RESULTS AND DISCUSSION

The moisture of the *E. urophylla* wood samples along the drying period was higher than those of *C. citriodora*, but those had higher basic density values (Table 2).

Moisture losses showed higher values in the first days of drying for both materials. During this period, the wood has high quantity of free water, requiring low energy expenditure for its removal and resulting in high loss of moisture per unit of time (ANANIAS et al., 2013; ENGELUND et al., 2013). This trend was also reported for *Eucalyptus urophylla* logs (REZENDE et al., 2010), *Betula papyrifera* flakes (BEDANE et al., 2011) and *Eucalyptus cloeziana*, *Eucalyptus pellita* (REDMAN et al., 2010) and *Paulownia fortune* (TARIA et al., 2015) lumber.

The *C. citriodora* and *E. urophylla* materials had higher moisture at the base, followed by the middle and top of their logs. However, the moisture distribution pattern in the axial direction may vary for *C. citriodora* and *E. urophylla* logs (ZANUNCIO et al., 2013).

Logs with smaller diameter, removed at 100% of the commercial height of the log showed faster drying, reaching values near the equilibrium moisture content after 90 days of drying, 17.07% for *C. citriodora* and 15.87% for *E. urophylla*. This occurred because the distance traveled by the water inside the wood is shorter, reaching the surface quickly and, thus, increasing drying rate (REZENDE et al., 2010).

The basic density of the *C. citriodora* logs was higher and their initial moisture lower than those of *E. urophylla*. A higher basic density implies in greater wood mass per volume unit and smaller spaces filled with free water in the wood and, therefore, lower initial moisture (ENGELUND et al., 2013). However, the lower volume of void spaces reduces the drying rate by hindering water exit (ZANUNCIO et al., 2015). The first effect was stronger, thereby the logs from base and middle of *C. citriodora* showed less moisture after 90 days of drying. Similar results were reported for *Cryptomeria japonica, Eucalyptus grandis, Eucalyptus urophylla* and *Tsuga heterophylla* wood (BERBEROVIC; MILOTA 2011; MUGABI et al., 2010; WATANABE et al., 2012; ZANUNCIO et al., 2013).

Reducing the wood moisture allows to transport higher dry mass, reducing fuel consumption and the number of trips to supply the pulp mill (Figure 1).

Reduction of fuel consumption per ton of dry wood transported per kilometer was higher in the early days of drying. After 15 days drying, fuel consumption per ton transported dropped from 0.124, 0.118 and 0.116 $L\cdot t^{-1}$ to 0.095; 0.086; 0.076 $L\cdot T^{-1}$ for *C. citriodora* logs from the base, middle and top, respectively. In the 75 days drying following, the fuel consumption per ton of dry wood transported reduced in 0.084; 0.077 and 0.075 $L\cdot T^{-1}$ in logs from the base, middle and top. The initial reductions in a short time were due to the large quantities of free water, easily removed by drying (ENGELUND et al., 2013). The *Eucalyptus urophylla* logs showed similar trend of those of *C. citriodora*.

Wood drying reduced the number of trips required to supply the pulp mill. The logs from the base have larger diameter, represent the largest proportion of the total wood volume and present a slower drying. In these logs, it was necessary a total of 483 and 526 trips per day to supply the pulp mill with freshly cut wood, however, after 90 days of drying, this number dropped to 355 and 380 trips for *C. citriodora* and *E. urophylla*, respectively. In addition to time and fuel economy, the reduced number of trips makes necessary a lower number of vehicles to supply the pulp mill with wood.

The *C. citriodora* logs from base and middle showed lower moisture after 90 days of drying, due to lower initial moisture and higher basic density (ENGELUND et al., 2013; ZANUNCIO et al., 2013). This reduces fuel consumption and the number of trips to supply the pulp mill. Thus, the selection of clones with high density can reduce transportation costs.

Logs of *C. citriodora* and *E. urophylla* from top lost a large amount of moisture in the first month, reaching moisture content near the equilibrium moisture content and reduced moisture losses in the next 60 days. Thus, segregate logs by size can allow using those with smaller

**TABLE 2** Longitudinal position of the logs (Pos.), basic density (D.), initial moisture (Initial %) and after 30, 60 and 90 days of drying of *Corymbia citriodora* and *Eucalyptus urophylla* logs.

| Material | Position | D ($g\cdot cm^{-3}$) | Initial (%) | 30 days (%) | 60 days (%) | 90 days (%) | Material | Position | D ($g\cdot cm^{-3}$) | Initial (%) | 30 days (%) | 60 days (%) | 90 days (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Eucalyptus urophylla* | Base | $0.528^{3.8}$ | $94.5^{4.4}$ | $57.6^{4.2}$ | $48.9^{4.1}$ | $40.4^{3.7}$ | *Corymbia citriodora* | Base | $0.665^{6.1}$ | $78.4^{6.8}$ | $43.0^{5.7}$ | $36.7^{5.4}$ | $31.1^{4.6}$ |
| | Middle | $0.571^{3.1}$ | $84.5^{5.4}$ | $40.4^{4.2}$ | $35.1^{4.0}$ | $29.2^{4.4}$ | | Middle | $0.683^{7.4}$ | $75.4^{5.5}$ | $29.7^{5.1}$ | $24.2^{4.9}$ | $20.4^{4.8}$ |
| | Top | $0.567^{3.1}$ | $80.9^{4.7}$ | $22.0^{2.2}$ | $16.4^{1.3}$ | $15.8^{1.2}$ | | Top | $0.673^{6.3}$ | $74.3^{6.7}$ | $18.5^{2.8}$ | $17.8^{1.1}$ | $17.0^{1.0}$ |

Values in superscript represent the coefficient of variation.

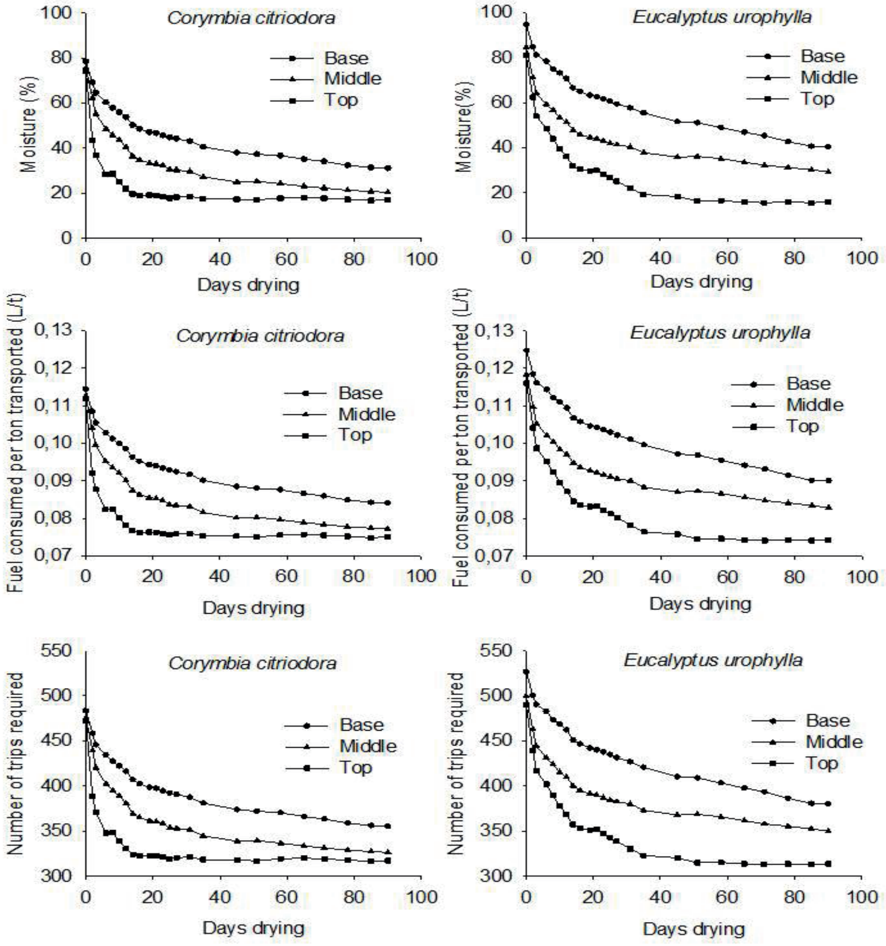

**FIGURE 1** Wood moisture, fuel consumption per ton of dry wood transported per kilometer and the number of trips to supply the pulp mill during 90 days of wood drying.

diameter in the short time for the pulp mill, optimizing harvesting and wood transport. This is important because keeping these logs in the field represent costs without the gain generated by reducing the wood moisture.

Models for wood moisture, fuel consumption per wood dry ton transported and the number of trips to supply the pulp mill showed high accuracy, with a correlation coefficient above 0.8521 and 0.9369 for *C. citriodora* and *E. urophylla*, respectively (Table 3). This agrees with that reported for drying in *C. citriodora* and *E. urophylla* logs, 0.826 and 0.951, respectively (REZENDE et al., 2010; ZANUNCIO et al., 2015). The *E. urophylla* materials have clonal origin therefore, lower variability and resulting in high accuracy of the models. By its turn, *C. citriodora* wood, originated from seeds, showed higher variability.

## CONCLUSION

Air drying was efficient to reduce the moisture content of wood. Moisture content of wood from the base and middle of *C. citriodora* logs were lower during the study period, resulting in lower transport costs than *E. urophylla*. Logs from the top showed high drying rate, reaching low moisture in the first month of drying and being available for transport thereafter. Models to estimating the moisture, fuel consumption and number of trips to supply a pulp mill based in days of drying showed high correlation coefficient and low standard deviation and can be used to estimate the forest transportation costs. Drying reduces transportation costs through forest fuel economy and lower number of trips and vehicles required to supply the pulp mill.

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**TABLE 3** Estimated models for log moisture, fuel consumption per ton of dry wood transported per kilometer and number of trips required to supply the pulp mill based in days of drying.

| Mat. | Pos. | Log moisture (%) | $r^2$ | σ |
|---|---|---|---|---|
| C. | Base | $Y = 79.16375383 + 0.413075077\times d - 8.90004506\times d0.5$ | 0.8521 | 5.19 |
| | Middle | $Y = 75.38412124 + 0.728924566\times d - 12.5048352\times d0.5$ | 0.9355 | 3.67 |
| | Top | $Y =64.55357990 + 1.144998815\times d - 15.3062756\times d0.5$ | 0.8711 | 4.69 |
| E. | Base | $Y = 95.16175671 + 0.258867562\times d - 8.18443588\times d0.5$ | 0.9369 | 3.76 |
| | Middle | $Y = 83.74174463 + 0.628872180\times d - 11.4660820\times d0.5$ | 0.9855 | 1.66 |
| | Top | $Y = 80.68107529 + 0.962381396\times d - 15.8636170\times d0.5$ | 0.9742 | 2.75 |
| Mat. | Pos. | Fuelconsumption (L·t$^{-1}$) | $r^2$ | σ |
| C. | Base | $Y = 0.114848560 + 0.000264792\times d - 0.00570516\times d0.5$ | 0.8521 | 0.00332 |
| | Middle | $Y = 0.112425719 + 0.000467259\times d - 0.00801592\times d0.5$ | 0.9355 | 0.00235 |
| | Top | $Y =0.105483064 + 0.000733974\times d - 0.00981172\times d0.5$ | 0.8711 | 0.00301 |
| E. | Base | $Y = 0.125103690 + 0.000165941\times d - 0.00524643\times d0.5$ | 0.9369 | 0.00241 |
| | Middle | $Y = 0.117783170 + 0.000403123\times d - 0.00735005\times d0.5$ | 0.9855 | 0.00106 |
| | Top | $Y = 0.115821202 + 0.000616911\times d - 0.01016899\times d0.5$ | 0.9742 | 0.00176 |
| Mat. | Pos. | Number of trips to supply the pulp mill | $r^2$ | σ |
| C. | Base | $Y = 485.2351666 + 1.118745000\times d - 24.1042887\times d0.5$ | 0.8521 | 14.05 |
| | Middle | $Y = 474.9986617 + 1.974170701\times d - 33.8672621\times d0.5$ | 0.9355 | 9.94 |
| | Top | $Y = 445.6659456 + 3.101038458\times d - 41.4544965\times d0.5$ | 0.8711 | 12.71 |
| E. | Base | $Y = 528.5630911 + 0.701099648\times d - 22.1661805\times d0.5$ | 0.9369 | 10.20 |
| | Middle | $Y = 497.6338917 + 1.703195487\times d - 31.0539721\times d0.5$ | 0.9855 | 4.49 |
| | Top | $Y = 489.3445789 + 2.606449614\times d - 42.9639626\times d0.5$ | 0.9742 | 7.45 |

d= days of drying; $r^2$: coefficient of correlation; σ: standard deviation; Mat=Material; C.=*Corymbia citriodora*; E.= *Eucalyptus urophylla*; Pos =Longitudinal position of the logs.

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