RELATIONSHIP BETWEEN CLIMATE VARIABLES, TRUNK GROWTH RATE AND WOOD DENSITY OF *Eucalyptus grandis* W. Mill ex Maiden TREES[1]

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ABSTRACT – Climatic conditions stimulates the cambial activity of plants, and cause significant changes in trunk diameter growth and wood characteristics. The objective of this study was to evaluate the influence of climate variables in the diameter growth rate of the stem and the wood density of *Eucalyptus grandis* trees in different classes of the basal area. A total of 25 Eucalyptus trees at 22 months of age were selected according to the basal area distribution. Dendrometer bands were installed at the height of 1.30 meters (DBH) to monitor the diameter growth every 14 days, for 26 months. After measuring growth, the trees were felled and wood discs were removed at the DBH level to determine the radial density profile through x-ray microdensitometry and then re-scale the average values every 14 days. Climatic variables for the monitoring period were obtained and grouped every 14 days. The effect of the climate variables was determined by maximum and minimum growth periods in assessing trunk growth. These growth periods were related with precipitation, average temperature and relative air humidity. The re-scaled wood density values, calculated using the radial growth of the tree trunks measured accurately with steel dendrometers, enabled the determination of the relationship of small changes in wood density and the effect of the climatic variations and growth rate of eucalyptus tree trunks. A high sensitivity of the wood density to variation in precipitation levels was found.

Keywords: Climate; Dendrometer; Wood

RELAÇÃO ENTRE VARIAVEIS CLIMÁTICAS, TAXA DE CRESCIMENTO DO TRONCO E DENSIDADE APARENTE DO LENHO DE ÁRVORES DE Eucalyptus grandis W. Mill ex Maiden

RESUMO – Os estímulos provocados na atividade cambial das plantas pelas condições climáticas promovem significativas alterações no incremento em diâmetro do tronco e nas características do lenho. O objetivo deste trabalho foi avaliar a influência das variáveis climáticas na taxa de crescimento em diâmetro do tronco e na densidade do lenho de árvores de ***Eucalyptus grandis*** *em diferentes classes de área basal. Foram selecionadas 25 árvores de eucalipto, de acordo com a distribuição de área basal, com 22 meses de idade onde foram instaladas faixas dendrométricas a 1,30 metros (DAP) para o monitoramento do incremento em diâmetro do tronco a cada 14 dias, em um período de 26 meses. Após o período de medição do incremento, as árvores foram derrubadas e retirados discos de lenho no DAP para a determinação dos perfis radiais de densidade aparente por microdensitometria de raios x e posterior re-escala dos valores médios a cada 14 dias. Variáveis climáticas referentes ao período de monitoramento foram obtidas e agrupadas a cada 14 dias. Na avaliação do incremento do tronco o efeito das variáveis climáticas foi determinado pela ocorrência de períodos de máximo e mínimo crescimento, estando relacionados com a precipitação, temperatura média e umidade*

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relativa do ar. A re-escala dos valores de densidade do lenho, aplicando-se o crescimento radial do tronco das árvores mensurado com precisão com dendrômetros de aço, permitiu determinar a relação das pequenas mudanças de densidade do lenho e o efeito das variações climáticas e da taxa de incremento do tronco das árvores de eucalipto, constatando-se uma alta sensibilidade da densidade do lenho em relação a variação dos níveis de precipitação.

Palavras-chave: Clima; Dendrômetro; Madeira.

1. INTRODUCTION

Evaluating and monitoring the productivity of forest stands is key to understand the individual reaction of trees to stimuli and changes in climatic conditions. The use of permanent dendrometers has proven to be an effective option in the continuous measurement of the growth in trunk diameter of tropical and temperate forest trees. Dendrometers enable assessing small changes in growth in reduced time intervals, and have high precision and low cost. Several studies have used dendrometers to evaluate the growth rate and pace of the trunks of tropical and temperate trees since the 1970s (MARIAUX, 1970; DÉTIENNE et al., 1989; BOTOSSO; TOMAZELLO FILHO, 2001). However, the studies using dendrometric bands in *Eucalyptus* species plantations are scarce. The study carried out by Sette Jr et al. (2010) with *Eucalyptus grandis* is highlighted, showing the seasonal diameter growth of tree trunks as a result of the periodic cambial activity caused by climatic stimuli.

The stimuli caused in the cambial activity of the plants by climatic conditions, especially by the water availability in the environment, cause significant changes in the trunk growth rate and wood characteristics (DREW et al., 2009, 2010; SETTE Jr, 2010). Therefore, studying the trunk diameter increment and wood characteristics in regards to climate variables is key to better understand the relationships between the processes. The seasonality of the cambial activity is a consequence of changes in temperature, photoperiod and precipitation, with endogenous factors inherent to each species controlling its growth rate (MARCATI, 2006). The growth rate and cambial activity are strongly regulated by temperature and by the water availability in the environment (DREW et al., 2009). Correlations between trunk growth rate and precipitation and temperature have been reported (WIMMER et al., 2002; DREW et al., 2008). Therefore, cambial activity depends on its phenological stage (canopy formed; leaves with expanded mature limbus), on water availability in the soil, precipitation and temperature levels and on the hours of light/day, which increases the rate of photosynthesis. Thus, the cambial activity is regulated by hormones and carbohydrates which induce higher rates of cambial cell division when moving towards the downward xylem flow, promoting changes in the characteristics and properties of the wood.

The relationship between wood structure and properties, and climate variables has been studied, where Baas (1973) was the pioneer. Subsequent studies, carried out in both tropical and temperate regions, found that environmental variations are reflected in wood properties and characteristics (WIMMER et al., 2002; DREW et al., 2008, 2009; SETTE Jr et al., 2010).

Density is considered one of the most important wood properties, as it provides information on other characteristics of the wood and is commonly used to determine wood quality. Microscopic analysis shows the anatomical structure of the growth rings of the wood. Growth rings are characterized by having a reduced percent vessel area, increased fiber percentage, thicker and smaller wall , thus increasing the wood density. Growth layers in the wood of eucalyptus trees are formed in response to climatic conditions, which have a significant effect of inducing cambial activity seasonality and, consequently, tree growth and development. The latewood growth rings have higher density, are formed in the water stress period, and are characterized by having smaller diameter and frequency of vessels (see LEAL et al., 2004 for an example in *Eucalyptus globulus* trees from Portugal). Increased water deficit in soil causes a reduction in the diameter of the vessels in the wood of *E. globulus* and *Eucalyptus nitens* trees, with the growth rings exhibiting lower/higher density in the beginning and end of the growing season (WIMMER et al., 2002). Therefore, wood density is strongly regulated by climatic conditions (DOWNES et al., 2000).

The objective of this study was to assess the influence of climate variables on the growth rate of trunk diameter and on wood density of *Eucalyptus grandis* trees in different basal area classes.

2. MATERIAL AND METHODS

2.1. Study Area

The increment in trunk diameter and the average of wood density of *Eucalyptus grandis* trees were assessed in a plantation deployed in April/2004, in 3x2m spacing, at the Experimental Station of Forest Sciences of Itatinga/SP, Department of Forest Sciences (Departamento de Ciências Florestais) of ESALQ/USP (23º 10' S and 48º 40'W, height of 857 m). The climate is characterized as humid mesothermal (Cwa), according to Köeppen, with average annual precipitation of 1.400 mm and average temperature of 16.2°C and 28.6°C in the coldest and hottest months, respectively. The soil is a medium texture Red Yellow Oxisol (200 g kg^{-1} clay) with sandstone lithology, Marilia formation, Bauru Group.

A total of 2,000 kg/ha dolomitic limestone were distributed in the soil of the experimental area before planting, by throwing and without incorporation. The other nutrients were applied three times in the first year (1/3 during planting, 1/3 at six months and 1/3 at 12 months), and consisted of 116 Kg K_2O, 80 kg P_2O_5, 45 kg N ($NH_4(SO4)_2$) and 45 kg FTE (BR-12)/ha as a source of micronutrients.

2.2. Trunk growth rate

Trunk diameter increment assessment began 22 months after planting, in 25 *E. grandis* trees. The trees were selected according to the basal area distribution (five trees per class), namely: (i) class 1 – 0.0029 m², (ii) class 2 – 0.0041 m², (iii) class 3 – 0.0049 m², (iv) class 4 – 0.0064 and (v) class 5 – 0.0079 m², installing permanent steel dendrometric bands at the height of 1.30 meters (DBH) of the trunk.

The dendrometric bands were made according to Botosso and Tomazello Filho (2001): Stainless steel bands of 12.7 x 0.15 mm (width and thickness) with scale in mm and reading accuracy of 0.2 mm, maintained under tension by a stainless steel spring of 100 x 8 mm (length and diameter) were installed on the tree trunk. The displacement of overlapping scales of the dendrometric bands was measured every 14 days to evaluate the trunk diameter increment of the trees, in the morning (8:00-10:00h) and following the same route. The data recorded were transferred to spreadsheets, processed into graphs, and then analyzed and interpreted to then be related with the climate variables and average wood density.

2.3. Wood density

The wood density was evaluated in wood samples cut 48 months after planting the 25 *E. grandis* trees (five trees per class of basal area) which were selected to receive the dendrometric bands to evaluate the growth of the trunk. The trees were cut and pruned, and wood disks were sectioned at the height of 1.30 m (Diameter at breast height – DBH) to determine the wood density by X-ray microdensitometry. Diametrical samples (20x10 mm, width x thickness) were delimited in wood disks and the samples were cut in cross sections. Then, thin wood samples (3.0 mm thickness) were sectioned transversely to the fiber alignment and stored in a climate chamber (20°C and 53% relative air humidity) until reaching 12% wood moisture balance. The wood samples were transferred to an x-ray equipment (Seifert JSO; 2.40 m distance from the X-ray film source) and x-rayed (5 min exposure, 18 Kv accelerating voltage of the tube, 12 mA cathode heating current). The radiographic films of the wood samples were submitted to a double beam X-ray microdensitometer Joyce Loebl MK3 to determine the wood density. These wood density values were grouped into 5% segments of the wood and used to build the radial profiles and to determine the average maximum and minimum wood density and the heterogeneity index (standard deviation of all the density values) for each segment and were later compared with the basal area classes, and climate and growth variables.

2.4. Re-scale of the wood density data

The approximate date wood formation (re-scale) may be inferred when the radial growth of the trunk is measured through dendrometric bands of trees from which samples were made to determine the wood density. The thicknesses of the barks of the radial samples cut to determine the wood density were measured and used to determine the linear regression equation (R^2=0.99) (eq. 1) which enabled the correction of radial growth data, removing bark thickness from the measurements. The re-scale of the average wood density enables obtaining values every 14 days, or according to the dendrometer reading date. Therefore, the values obtained may be related with the growth and climatic values, also every14 days.

R_{nb}=0.9096*R_{wb} (1)

where:

R_{nb} = radius with no bark (cm)

R_{wb} = radius with bark (cm)

2.5. Climate variables

The average maximum and minimum temperature values (ºC), accumulated precipitation (mm), relative air humidity (%) and volume of water in the soil at different depths (m^3/ha) from February/2006 to April/2008 were obtained from the Meteorological Experimental Station of Itatinga/SP (800 m from the experimental area) and grouped every 14 days to coincide with the readings of the dendrometric bands and then be related with the trunk diameter increment of the eucalyptus trees and wood density. The vapor pressure deficit was determined following Penman-Monteith (FAO, 1998) through eq. (2), the vapor saturation pressure calculated by eq. (3), using the average temperature, and the partial vapor pressure by eq. (4), using the relative air humidity.

$$VPD = (es - ea) \quad (2)$$

where:

VPD = vapor pressure deficit (kPA)

es = vapor saturation pressure

ea = partial vapor pressure

$$es = 0.611e^{\;17.27\,AT\,/\,AT\,+\,27} \quad (3)$$

Where:

AT = average temperature (°C)

$$ea = \frac{RH}{100} * es \quad (4)$$

Where:

RH = relative air humidity (%)

2.6. Statistical Analysis

The software JMP (SAS, 1997) was used for the statistical analysis of the results, where the "outliers" and heterogeneity of variance were assessed. The analysis of variance (ANOVA) was used to evaluate the wood density results, assessing the effect of the basal area classes. The Tukey test was used at a 95% probability level. Multiple regression analyses (stepwise) were carried out to select the variables that explain the trunk diameter increment of the trees and the average wood density.

3.RESULTS

3.1. Trunk growth rate

The values of current and accumulated DBH increment in the trunk of the eucalyptus trees in the basal area classes 1, 2, 3, 4 and 5, obtained by measuring the dendrometric bands every 14 days for 26 months (February 2006 to April 2008), are shown in Figure 1 A, B. Periods characterized by temporal variations in the maximum (0.04-0.18 cm; February to May, September and beginning of July, October and December 2006, November, beginning of April, May and end of July and August 2007, and beginning of February 2008) and minimum increments (0.00-0.09 cm; mid-August and late October, and November 2006, January, late February, September and October 2007) of the trunk of Eucalyptus trees (Figure 1A) were observed.

Likewise, the results show a greater difference in current DBH increment in the tree trunk for the five basal area classes in the periods of greatest growth rates. Differences decreased significantly in the periods of lower growth rates, with larger trees (classes 4 and 5) suffering greater reduction than the smaller trees (classes 1, 2 and 3) (Figure 1A).

The initial increment in DBH of the tree trunks (Figure 1B) of the classes 1, 2, 3, 4, and 5 was 5.2, 6.6, 7.6, 8.7 and 9.7 cm, respectively, and represent the differences existing in the 22nd month of tree growth. The trees of the higher basal area classes (4 and 5) already had larger trunk diameters in the initial phase than the other classes. The tree dimensions were (basal area classes) were evaluated for 26 months. The trees in the classes 1, 2, 3, 4 and 5 had diameter values of 7.5, 10.0, 11.9, 13.4 and 14.8 cm, respectively, on the 48th month of growth. In this phase, the differences observed in the initial period (22nd month) remain, with the trees of the largest classes of basal area exhibiting larger trunk diameters. The dendrometric bands at the end of the monitoring period are a result of the initial diameters and the different increment rates.

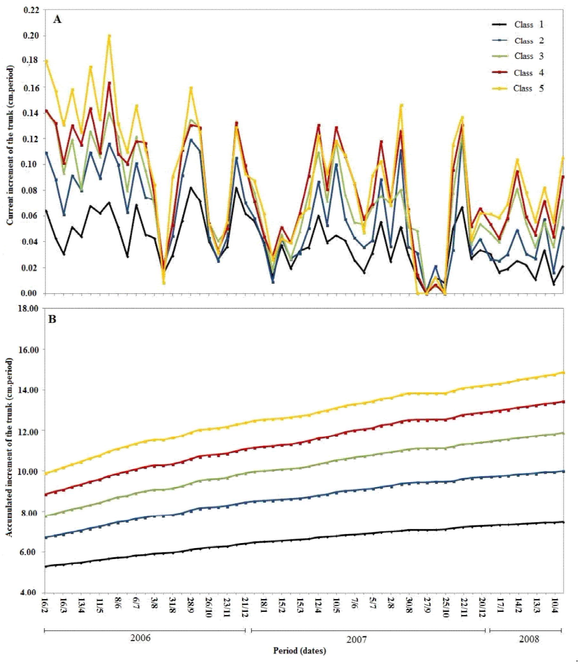

Figure 1 – Current (A) and accumulated (B) trunk increment in DBH of *Eucalyptus grandis* trees every 14 days per basal area class, in the 26-month period.
Figura 1 – *Incremento corrente (A) e acumulado (B) do tronco no DAP das árvores de **Eucalyptus grandis** a cada 14 dias por classe de área basal, no período de 26 meses.*

The relationship between the increment in the trunk DBH of the trees and the climate variables, and its order of importance was assessed through the multiple regression analysis, considering each average value for the 14-day period as a replicate (Table 1).

The non-significant variables were removed from the regression analysis, namely volume of water available in the soil layers, maximum and minimum temperature, and vapor pressure deficit. These variables were considered of lesser interest in determining the variation of the trunk diameter increment. Therefore, the variables precipitation, average temperature and relative air humidity were selected to explain trunk diameter increment, in a Stepwise regression (5% probability) to comprise the regression model (eq. 5). These three variables explain 52% of the total variation in trunk diameter increment. The variables precipitation, average temperature and relative air humidity are responsible for 37, 34 and 29 % of the variation (Table 1)

$$Inc=-0.1378-0.0127*Prec-0.0041*Taverage+0.0043*RH \quad (5)$$

Where:

Inc = growth

Prec= precipitation (mm)

Taverage = Average temperature (°C)

RH = relative humidity (%)

3.2. Wood density

The results of the average variation, maximum and minimum wood density and the heterogeneity index of the wood of the trunk on the DBH level of 48-month old eucalyptus trees, in the five classes of basal area are shown in Table 2. The values of average and maximum wood density did not differ statistically, with average

Table 1– Multiple regression analysis of the trunk growth (dependent variable) and the climate variables (independent variables), based on the means of the 14-day periods.
Tabela 1 – *Análise de regressão múltipla entre o incremento do tronco (variável dependente) e as variáveis climáticas (variáveis independentes), com base nos valores médios por período de 14 dias.*

Steps	increment at DBH	Avera Temp	Max Temp	Min Temp	Prec.	0-15*	0-50*	0-150*	0-300*	Air humidity	Pressure deficit
1	3.58	13.25	30.10	45.67	1.45	2.06	1.82	0.87	0.94	0.17	0.91
2	3.40	13.47	30.48	46.13	1.31	1.85	1.77	0.83	0.76	—	0.91
3	20.14	5.93	—	21.16	8.51	14.00	18.61	5.37	6.27	—	0.87
4	22.79	—	—	22.00	10.59	15.14	20.00	3.22	6.52	—	0.81
5	25.14	—	—	24.00	11.48	16.13	14.97	—	8.24	—	0.75
6	31.13	—	—	27.00	18.81	17.48	—	—	5.63	—	0.69
7	33.17	—	—	29.14	20.05	17.99	—	—	—	—	0.61
8	37.15	—	—	34.16	29.04	—	—	—	—	—	0.52

* water volume available in the layers 0-15, 0-150, 0-150 and 0-300cm of the soil
a) the values located below the independent variables are standardized coefficients (beta) and represent the proportion which each variable contributes to determine the dependent variable; b) the symbol "—" indicates that the independent variable was non-significant for $p<0.05$

Table 2 – Mean, maximum and minimum wood density and heterogeneity index of 48-month old the eucalyptus trees, per basal area class.
Tabela 2 – *Densidade aparente média, máxima, mínima e índice de heterogeneidade do lenho, aos 48 meses, por classe de área basal.*

Basal area class	Wood density (g/cm³)			
	Mean	Maximum	Minimum	Heterogeneity index
1	0.52 **a** (0.03)	0.60 **a** (0.01)	0.43 **a** (0.04)	0.05 **ab** (0.01)
2	0.46 **a** (0.04)	0.56 **a** (0.05)	0.35 **b** (0.03)	0.06 **bc** (0.01)
3	0.50 **a** (0.05)	0.58 **a** (0.07)	0.41 **a** (0.03)	0.05 **a** (0.01)
4	0.46 **a** (0.04)	0.57 **a** (0.03)	0.36 **b** (0.02)	0.06 **bc** (0.01)
5	0.48 **a** (0.04)	0.59 **a** (0.03)	0.36 **b** (0.02)	0.06 **c** (0.01)
Mean	0.48	0.58	0.38	

values ranging from 0.52-0.60, 0.46-0.56, 0.50-058, 0.46-0.57 and 0.48-0.59 g.cm^{-3} in the classes 1, 2, 3, 4 and 5, respectively. On the other hand, the values of the minimum wood density were statistically different and the heterogeneity index (wood density changes along the radial direction of the wood) show average and significant values of 0.05-0.06 in the five classes.

The x-ray densitometry profiles show a radial variation model characterized by higher values in the pity region (0.50-0.65 g.cm^{-3}), reduction and stabilization (0.40-0.50 g.cm^{-3}) and an increase toward the bark (0.65-0.80 g.cm^{-3}) (Figure 2; See example of tree in class 3).

The following non-significant variables were removed from the regression analysis: volume of water available in the soil layers, average, maximum and minimum temperature, vapor pressure deficit, relative

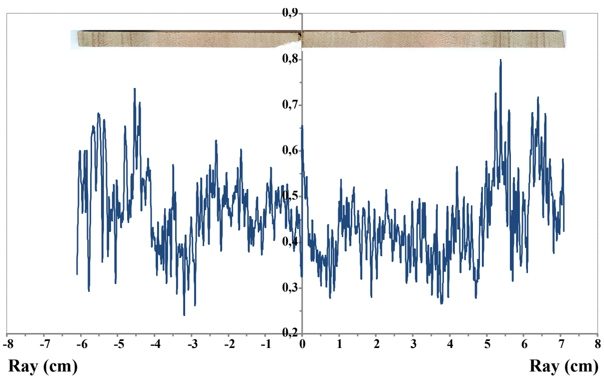

Figure 2 – Profile of the average of wood density of *Eucalyptus grandis* trees of the basal area class 3.
Figura 2 – *Perfil da densidade aparente média do lenho de árvore de* ***Eucalyptus grandis*** *da classe de área basal 3.*

air humidity and DBH increment. These variables are of lesser interest in determining density variation. The variable precipitation was selected to explain the average wood density in the regression model (eq. 6), explaining 37.0 % of the total density variation.

$$Daverage = 0.5199 - 0.0002*Prec \quad (6)$$

Where:

Daverage = wood density (g.cm^{-3})

Prec= precipitation (mm)

4. DISCUSSION

4.1. Trunk growth rate

The effect of climate variables on the increment in the DBH of tree trunks may be determined by maximum and minimum growth periods. The periods of maximum increment in the tree trunks (February to May, September, early July, October and December 2006, November, early April, May and late July, and August 2007 and early February 2008) may be explained by the phenological stage of the tree (formed canopy and mature leaves with expanded limbo), by water availability in the soil, by the precipitation levels and by the hours of light/day, which increases photosynthesis rates. Therefore, the stimulation tree trunk growth is due to hormones and carbohydrates which, when moving in the direction of downward phloematic flow, increase rates of cambial cell division, increasing the trunk diameter growth.

Precipitation levels were limiting in the period of minimal tree trunk growth (mid-August and late October, and November 2006, and January, late February

September and October 2007), with average and accumulated values of 12.3 and 184.5 mm, respectively. This trunk diameter growth response has been observed in several species of *Eucalyptus* trees, analyzed using dendrometers (DREW; PAMMENTER, 2007). The frequency of the cambial activity and the consequent diametric tree growth is a result of changes in temperature, day length and precipitation, with the endogenous factors inherent to each species controlling its growth rate.

The results showed that larger trees have a greater potential (root system - shoot) to assimilate growth factors, be it water, soil nutrients and/or sunlight (Figure 1). A greater homogeneity of the growth of the trees in stands and productivity maximization are goals of sustainable forest management.

The relationship between the increment in the tree trunk DBH and the climate variables was verified using a multiple regression analysis (Table 1). The results of the multiple regression show that the maximum and minimum variations of the increment in the tree trunk DBH are related with precipitation, average temperature and relative air humidity. Drew and Pammenter (2007) observed an increase in trunk diameter and in the cambial activity with greater water availability in eucalyptus tree clones in Australia. The growth rate and cambial activities are highly regulated the temperature of the environment (DREW et al., 2009). Likewise, the growth rate of the tree trunk was correlated with precipitation and temperature, and these climate variables increase photosynthesis rate and, then, cambial activity (WIMMER et al., 2002; LACLAU et al., 2005; DREW et al., 2008; SETTE JR et al., 2010). The trunk growth pattern of *E. globulus* and *E. nitens* trees was assessed daily through specific dendrometers (DOWNES et al., 1999). Precipitation explained 22 to 36 % of the daily trunk diameter increment variation observed for *E. globulus* and *E. nitens*, and this result was attributed to the growth increment recorded immediately after rainfall. It is worth mentioning that ecophysiological models must be developed to explain the tree growth variation in regards to climate conditions. However, it was not an objective of this study. The interaction between climate variables and the cambial growth of Eucalyptus trees is complex. Therefore, a better understanding of the interaction between the variables and cambial growth on the physiological level of the tree is required to better comprehend cambial and, thus, trunk growth.

4.2. Wood density

The average and maximum wood density, considering the categorization of 48-month old trees per basal area, did not differ statistically (Table 2). Therefore, the average and maximum wood density are not influenced by the size of the eucalyptus trees. The minimum wood density and the heterogeneity index were significant for some basal area classes. However, there was no consistent variation trend. The amplitude of variation of the wood density shows alternate growth bands on the wood (Figure 2) detected by the accurate X-ray microdensitometry method (readings at 100 μm intervals). The average wood density is not influenced or is weakly correlated with the growth rate of *E. grandis* trees (TAYLOR, 1974; HILLIS; BROWNA, 1984). However, some exceptions have been reported.

The average of wood density recorded in this study (0.48 $g.cm^{-3}$) (Table 2) are lower than the reported by Tomazello Filho (2006) (0.65-0.70 $g.cm^{-3}$). This difference is related with the contents of adult and juvenile wood and to the age of the trees, as the juvenile wood formed in Young trees usually have lower density than the adult trees.

The x-ray densitometry profiles (Figure 2) show a radial variation model similar to Alzate (2005) and Tomazello Filho (2006), who reported lower wood density values for the internal area of the tree trunk (juvenile wood), followed by a transition area and a gradual increase in density towards the bark (adult wood) for *E. grandis* and *E. urograndis* trees. Therefore, variation pattern of the wood density of 48-month old Eucalyptus trees, is characterized by the presence of juvenile wood and early transition. The pity density value may be a consequence of the occurrence of crystals and starch in the parenchyma cells (TOMAZELLO FILHO, 2006; TOMAZELLO FILHO et al., 2008; SETTE JR et al., 2012) in the wood of E. *grandis* trees, in addition to wood density fluctuations in the profiles due to the variations in vase diameter/frequency and the occurrence of thicker wall fiber bands.

The radial profiles of the variation of wood density enable the assessment of important and meaningful responses of eucalyptus tree growth (Figure 2). Larger density values (peaks) defining an internal (pity until 3.0-4.0 cm of the ray) and external (from 4.0 cm) region of the wood of tree trunks are observed. The inner region of the trunk wood is common to all trees, which have similar variation of the wood density, comprising the juvenile wood and no demarcation of the growth layers. The minimum and maximum apparent density of the wood in the inner region is 0.25-0.45 and 0.55-0.65 $g.cm^{-3}$, respectively. The wood density variation pattern in the external region of the wood of the eucalyptus trees is typical of all the trees of the different basal area classes, with clear growth layers.

The random effects of the high residue is one of the most important characteristics of the Analysis of Variance carried out for the wood density, as it is one of the main variation sources (39.1 % of the total variation). The natural variability of the wood density is inferred to be usually high, and such variation is also due to factors other than the ones considered in this study. Therefore, the evaluation of other factors that may be influencing the wood density was necessary, e.g., the climate variables and growth rate of trees.

A multiple regression analysis was carried out to explain the relationship between average wood density and tree trunk growth, and the climate variables (re-scale), as well as to assess the level of importance (Table 3). Precipitation was selected to compose the regression model, and is inversely related with wood density, showing that a lower/higher precipitation level implies in a higher/lower average density of the wood of eucalyptus trees. A high sensitivity of wood density towards precipitation variation is confirmed. Similar results have been reported by Drew et al. (2009) using the re-scale method in Australia for density data of the wood of *E. globulus* trees*,* as wood properties are sensitive to changes in environmental conditions, especially water availability in the environment.

The re-scale of the average of wood density is critical, and especially important for ecophysiology studies of eucalyptus species. The growth layers are not always formed every year in the wood of eucalyptus trees. In addition, the re-scale of wood density values, using the radial growth of tree trunks accurately measured with steel dendrometers, enabled determining the relationship of small changes in wood density and the effect of climate variations and trunk growth rates of eucalyptus trees. The re-scale of the average wood density values of the wood proved to be efficient to relate to climatic variables, despite the high variability of wood density values between the two rays in densitometry profiles. Due to its importance, analyzing the relationship between climatic variables and wood density in other weather conditions and other species is recommended.

5. CONCLUSIONS

The *trunk growth rate* in the level of the DBH of *E. grandis* trees was (i) greater in larger trees when compared to the trees in the remaining basal area classes, and (ii) affected by seasonality, mainly precipitation, average temperature and relative air humidity, with maximum and minimum increment periods. The *average*

Table 3 – Multiple regression analysis of the average of wood density (dependent variable), growth in trunk diameter and the climate variables (independent variables), based on the means of the 14-day periods (re-scale).
Tabela 3 – *Análise de regressão múltipla entre a densidade aparente média do lenho (variável dependente), o incremento do tronco e as variáveis climáticas (variáveis independentes), com base nos valores médios por período de14 dias (re-escala).*

Steps	increment at DBH	Avera Temp	Max Temp	Min Temp	Prec.	0-15*	0-50*	0-150*	0-300*	Air humidity	Pressure deficit	R^2
1	2.00	3.44	15.12	10.72	3.54	1.24	3.73	2.68	0.00	26.41	31.10	0.58
2	2.00	3.44	15.12	10.72	3.54	1.24	3.73	2.68	—	26.41	31.10	0.58
3	2.11	3.26	14.94	10.63	3.54	—	4.88	2.68	—	26.34	30.84	0.58
4	2.23	3.82	15.62	11.58	4.89	—	2.44	—	—	27.41	32.09	0.57
5	2.62	4.34	16.85	10.39	5.55	—	—	—	—	27.35	32.90	0.55
6	2.82	—	16.91	8.23	6.47	—	—	—	—	29.65	35.96	0.51
7	6.82	—	17.05	—	10.57	—	—	—	—	30.40	35.27	0.47
8	14.84	—	—	—	22.58	—	—	—	—	35.48	27.10	0.46
9	—	—	—	—	29.06	—	—	—	—	44.44	26.50	0.41
10	—	—	—	—	63.23	—	—	—	—	36.76	—	0.37
11	—	—	—	—	100.00	—	—	—	—	—	—	0.37

* water volume available in the layers 0-15, 0-150, 0-150 and 0-300cm of the soil.
a) the values located below the independent variables are standardized coefficients (beta) and represent the proportion which each variable contributes to determine the dependent variable; b) the symbol "—" indicates that the independent variable was non-significant for $p<0.05$.

of wood density of *E. grandis* trees was not affected by basal area classes (no significant differences). The radial profiles of the wood density are characterized by higher values in the region near the pity, reduction and stabilization of the values, followed by an increase towards the bark. The *re-scale of the wood density values*, using the radial growth of the tree trunks accurately measured with steel dendrometers, enabled determining the relationship of small changes in wood density and the effect of climate variations and trunk growth rates of eucalyptus trees. A high sensitivity of wood density towards precipitation variation is confirmed.

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