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Growth Stress in *Peltophorum dubium* and its Correlation with the Growth Variables

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ABSTRACT

The exploitation of valuable native timber species in forest restoration projects has emerged as a promising strategy to make restoration financially viable. There are few studies regarding the quality of timber from restoration plantations. The aim of this study was to analyze growth stresses by determining the longitudinal residual strain (LRS) and evaluate their correlation with the growth variables in the species *Peltophorum dubium* (Spreng.) Taub in a 14-year old restoration plantation. Eighteen individuals were evaluated, determining the following variables: diameter at breast height (DBH), bark thickness, average annual growth in diameter (IMA) and annual periodic growth in diameter (IPA $_{2012-2015}$). The LRS was determined by the extensometer (CIRAD-Forêt), on DBH height and in the north-south direction of each tree. The LRS average was 0.072 mm, within the range of expected wood values for sawmilling. There was a significant positive correlation between the LRS, DBH and IMA.

Keywords: extensometer, canafístula, increase in diameter.

1. INTRODUCTION

The restoration of degraded forest ecosystems and landscapes has emerged as a promising strategy to face the global environmental crisis that has threatened human wellbeing and biodiversity conservation (Suding et al., 2015; Chazdon et al., 2016). In Brazil, ambitious restoration programs, such as the Atlantic Forest Restoration Pact (Melo et al., 2013), and legal requirements to restore a total of 21 million hectares of native ecosystems in private landholdings according to the Native Vegetation Protection Law (Brancalion et al., 2016), are examples of national scale initiatives. However, high implementation costs and negligible economic returns for farmers have limited the expansion of restoration programs. In the case of tropical forests, the exploitation of valuable native timber species in forest restoration projects has emerged as a promising strategy to make restoration financially viable (Brancalion et al., 2012; Lamb et al., 2005), but little is known about the quality of the timber from restoration plantations.

The main factor that decreases income for sawmills during timber processing is the occurrence of top cracks and warping observed in the wood after felling, which compromises the quality of the wood, contributing to the depreciation of the value of the material and limits its use in a lumber production. These effects are caused by growth stresses (Trugilho et al., 2006). Growth stresses are natural forces acting on the tissues of the trees that are intended to support and stabilize the trunk (Lima et al., 2004). These mechanical stresses are generated during tree growth in response to environmental (light, wind and slope) and silvicultural (thinning, pruning and density) (Souza, 2002) agents. They are in balance when the tree is standing, but when it is cut, deformations and cracks in the tops of the trunks occur immediately as a result of the steady state modification that existed during growth (Ferrand, 1983). In this context, it is necessary to study this phenomenon in order to assess its relationship with tree growth, and thus try to minimize its effects, leading to improved product quality, adding value and increasing competitiveness (Rocha & Tomaselli, 2002).

The most widely used method for indirect evaluation of growth stresses is the extensometer (Trugilho, 2005). This method was developed by the Centre de Recherche Agronomique in Cooperation Internationale Pour Le Développement - CIRAD-Fôret. Due to its easy use, speed of data collection in the field and the reliability of results, the method has been used for genetic studies and selection of eucalyptus clones (Souza, 2002; Pádua et al., 2004; Trugilho et al., 2006; Rodrigues et al., 2008). Studies relating longitudinal residual strain (LRS) with wood splitting indices, aiming at increasing the quality of the wood and the yield for log sawing also use this tool (Lima et al., 2013; Beltrame et al., 2015; Silva et al., 2016). However, LRS has mostly been assessed with an extensometer in *Eucalyptus* trees, which limits the reliability of its use for species with other characteristics, including many native valuable timber species.

The use of non-destructive methods of timber quality evaluation, such as extensometer to measure LRS, would be particularly important to assess timber quality in cultivated native trees because most of the old mixed plantations, when estimating the silvicultural potential of native trees (Silva, 2013), are located in Areas of Permanent Protection, where cutting trees is not allowed.

One of the most promising native trees for timber production in plantations is the canafístula tree (*Peltophorum dubium* - Fabaceae), which produces high quality timber in native forests and productivity of 19.60 m^3/ha/year in plantations (Revista da Madeira, 2007). In Ruchel (2003) studies on the evolution of the use and utilization of timber species, the deciduous forest of the Upper Uruguay ranked canafístula amongst the eight highest priority species for lumber. However, there is no information about the quality of canafístula trees in plantations. In this sense, scientific studies that aimed to boost the measurement variables and the relationship between the forestry and timber industries becomes necessary (Mendonça, 2006).

Therefore, the objective of this study was to determine the longitudinal residual strain as an indicator of growing stresses and analyze their correlation with the growth variables of 14-year old canafístula trees in a restoration plantation.

2. MATERIAL AND METHODS

2.1. Study sites and species

Peltophorum dubium is a native tree popularly known as canafístula, which belongs to the legume family (Fabaceae) and subfamily Caesalpinioideae, has extensive natural occurrence, from the state of Bahia to Rio Grande do Sul, often found in semi-deciduous forests (Carvalho, 2003). The species have fast growing and is considered secondary initial (Durigan & Nogueira, 1990), but with pioneering characteristics (Marchiori, 1997), being abundant in secondary formations, but with few individuals, usually with large proportions, occupying the dominant strata of the canopy of primary forest. It plays a pioneering role in open areas, roosts and degraded forests. (Carvalho, 2003). We sampled 18 canafístula trees in a 14-year old restoration plantation established in a farm located in the municipality of Descalvado - SP (21° 54' 14" S and 47° 37' 12" W), at 685 m of altitude (Cidade-Brasil, 2016). According to the climatic classification of Koeppen, the municipality is classified as Cwa, with an average temperature of 21.4 °C and average rainfall of 1508.7 mm, characterized as having a rainy summer, with average rainfall of 211 mm and dry winter, with average of 31.8 mm (CEPAGRI, 2016). The study area, was a mixed plantation of approximately 100 native species, spaced 3 m × 2 m without fertilization.

2.2. Measurements

The evaluated growth variables were the diameter at breast height (DBH), the mean annual increment (MAI) and the periodic annual diameter growth in the 3-years ($IPA_{2012\text{-}2015}$). The circumference at breast height (CBH), 1.30 m above the ground, was obtained using a tape measure; then, the data was transformed into DBH.

To evaluate the growth of the species, we calculated the mean annual growth (MAI), dividing the DBH by tree age, and annual periodic growth in diameter ($IPA_{2012\text{-}2015}$) from two measurements: for the years 2012 and 2015. The data from 2012 was obtained from the research conducted by Silva (2013), and we used the same trees, which had been individually tagged and geo-referenced. Equation 1 was used to calculate the $IPA_{2012\text{-}2105}$.

$$IPA_{2012-2015} = \frac{df - di}{P} \qquad (1)$$

legend: $IPA_{2012\text{-}2015}$ = Annual diameter growth (cm / year); df = DBH evaluated at the end of the growth period (cm); di = DBH evaluated early in the growth period (cm); P = measured range (years).

The LRS measurements were performed on living trees through the extensometer device, developed by the Centre de Recherche Agronomique in Cooperation Internationale Pour Le Développement - CIRAD-Fôret. When conducting the test, a portion of the tree bark was initially removed and at this time, the thickness of the bark was measured using a digital caliper with a precision of 0.01 mm. A window of rectangular shape measuring approximately 8 cm × 20 cm was made by removing bark,, to fix two metal pins, at a distance of 45 mm, arranged along the longitudinal direction of the trunk. Subsequently, the extensometer was supported on the upper pin and its dial indicator reset. Then a hole was made between the metal pins with the aid of a bow drill (hand drill) with a 20 mm drill bit. After drilling, the inner tension of the tree was released and recorded using an indicator clock. Measurements of longitudinal residual strain (LRS) were performed at the time of DBH being collected by tree along the north-south direction. The measurements were performed with no wind, as the air movement causes the internal support forces to oscillate the tree and consequently oscillates the clock display, which impairs reading.

3. RESULTS AND DISCUSSION

The average observed in the growth in diameter (Table 1) in this study was within the range expected for the age studied (14 years) compared with data from the literature. In prior research, the average diameter growth for canafístula of different ages was 1.83 cm / year (at age 8) (Costa et al., 2010); 0.70 cm / year (to 12.9 years) (Ferreira et al., 2007); 0.86 cm/ year (to 24 years) (Senna et al., 2012); 0.96 cm / year (to 11 years) (Sebbenn et al., 1999). Gurgel (1975) noted that the growth of canafístula at 7 years is intense, observing that 2-year old canafístula trees had a diameter growth of 2.40 cm / year. From 21-years old the value decreased to 0.90 cm / year.

Diameter growth generally tends to be greater during the first years following planting and drops over time and with the development of the tree (Senna et al., 2012).

This fact was observed in this study by comparing the IPA $_{2012\text{-}2015}$ and MAI values (Table 1), where growth over the last three years, represented by the IPA $_{2012\text{-}2015}$ was lower than the average annual increase (MAI) based on the age of the tree. Therefore, there is a very high growth rate for the diameter of canafistula, especially during early years of growth, decreasing over the course of time but still considered as rapidly growing.

The average LRS (0.072 mm) found for *Peltophorum dubium* (Table 1) was close to those values obtained when working with *Eucalyptus* clones and higher than well-known hardwood species. The lower the LRS rate, the lower the propensity to cracking, improving the quality of wood for timber and therefore raising the market value of the wood. The mean LRS of *Eucalyptus* clones for different ages (3, 5, 7, 8 and 9) was 0.065 mm (Cardoso et al., 2005); 0.076 mm; to 7.6; 4.3 and 4 years (Pádua et al., 2004); 0.071 mm to 8.5; 11 and 15 (Lima et al., 2004); to 10. 5 years of age, LRS ranged from 0.066 to 0.125 mm (Trugilho et al., 2006). For other hardwood species, the average value of the canafistula LRS was superior in comparison with Teak trees (*Tectona grandis* L. F.) at 14 years of age that showed an average LRS of 0.047 mm (Flórez, 2012). The Australian cedar (*Toona ciliata*) at 2 and 5 years old has an average LRS of 0.056 mm (Gonçalves, 2009). The LRS in black wattle trees (*Acacia mearnsii*), at 4 and 7 years old, was 0.066 mm (Delucis et al., 2015).

The difference in behavior of the growth stresses between species is normal, suggesting that these can be controlled by genetic factors (Chafe, 1979). Lima et al. (2004) demonstrated that the LRS varied as a function of genetic material into five *Eucalyptus* clones. Trugilho et al. (2006) and Pádua et al. (2004) found the high heritability of LRS in *Eucalyptus* clones, concluding that this feature has a strong genetic control.

The average value found for the LRS of canafistula was lower than that obtained by Silva et al. (2016) for two species of African mahogany at 19 years of age, *Khaya ivorensis* (0.082 mm) and *Khaya senegalensis* (0.084 mm). The authors found positive but not significant relationships, between the indices of top cracking of logs and LRS. They also concluded that the values permits the use and quality of African mahogany for the production of lumber. In this sense, compared with the LRS found in this study, canafistula wood has the potential to produce lumber and shows potential for use in timber production as well as making tropical forest restoration economically viable.

A positive and significant correlation between the DBH and LRS (r = 0.471) (Figure 1) and between LRS and MAI (r = 0.471) was observed. No significant correlation between the LRS and other variables was observed (Table 2).

Table 1. Average DBH, LRS, bark thickness and diameter growth for 18 canafístula trees.

	DBH (cm)	LRS (mm)	Bark thickness (mm)	IPA $_{2012\text{-}2015}$ (cm/year)	MAI (cm/year)
Average	23.74	0.072	6.99	1.09	1.70
Minimum	12.80	0.025	4.56	0.01	0.91
Maximum	44.56	0.135	10.49	2.68	3.18
S	10.92	0.037	1.43	0.84	0.78
CV (%)	45.99	51.097	20.42	77.04	45.99

Legend: DBH: diameter at breast height (1.30 m); LRS: longitudinal residual strain; IPA $_{2012\text{-}2015}$: regular annual diameter growth during the period 2012-2015; MAI: average annual growth; S: standard deviation; CV: coefficient of variation (%).

Table 2. Pearson correlation between DBH, LRS, bark thickness and diameter growth.

	DBH (cm)	LRS (mm)	Bark thickness (mm)	IPA $_{2012\text{-}2015}$ (cm/year)	MAI (cm/year)
DBH (cm)	1	0.471*	0.396^{ns}	0.689*	1
LRS (mm)		1	0.139^{ns}	0.206^{ns}	0.471*
Bark thickness (cm)			1	0.301^{ns}	0.396^{ns}
IPA $_{2012\text{-}2015}$ (cm/year)				1	0.689*
MAI (cm/year)					1

Legend: DBH: diameter at breast height (1.30 m); LRS: longitudinal residual deformation; IPA $_{2012\text{-}2015}$: periodic annual growth in diameter in the period 2012-2015; MAI: average annual increment; *5% significance; ^{ns}no significant.

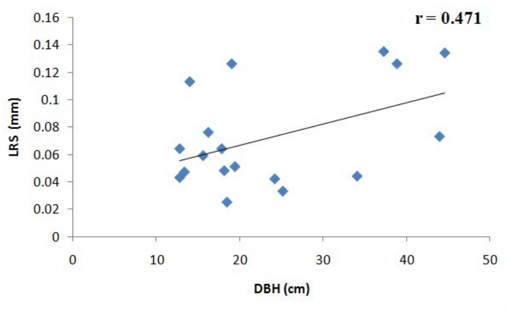

Figure 1. Correlation between DBH and LRS.

Malan & Hoon (1992), in research with *Eucalyptus* spp., observed a significant correlation between the average annual increase in the diameter of the living trees and cracks in the tops in trunks.

Vidaurre et al. (2015) analyzing the *Eucalyptus benthamii* at 5 years of age, found a correlation of 0.368 between the maximum LRS and DBH values. Muneri et al. (2000) studied *Eucalyptus cloeziana* at 4 years of age finding a significant correlation with LRS and DBH (r = 0.51).

On the other hand, some studies have shown a significant negative correlation between the DBH and the LRS in *Eucalyptus* (Trugilho et al., 2004; Silva, 2008; Carvalho et al., 2010; Delucis et al., 2015).

The LRS is influenced by growth factors which, depending on the species, may have a negative or positive impact.

The causes of growth stress levels are not well understood, although there is strong evidence that they are linked to the genotype, age, size of the trunk, growth rate and inclination of trunks (Rech & Silva, 2001).

This study noted that for 14-year old canafistula trees, the growth rate is a factor which influences the LRS, the higher growth causes largest increases of LRS. It was found that for $IPA_{2012-2015}$, the growth decreased over a period of three years. (Table 1) Therefore, there was no significant correlation between LRS and diameter growth over the last 3 years ($IPA_{2012-2015}$) (Table 2).

The LRS tends to be lower for canafístula trees when its growth rate diminishes, a phenomenon related to tree age. According to Rech & Silva (2001) the internal tensions have greater intensity in younger trees, considerably reducing maturation. Based on this information, we can minimize the effects of growing stresses using silvicultural treatments, or plan the cutting of trees at an older age, to increase the quality and value of canafístula wood.

4. CONCLUSIONS

For the LRS of the canafístula trees evaluated in this study, the age of 14 years was close to the values observed in *Eucalyptus* clones. In this respect, when compared with other species used in the timber industry, canafistula wood has the potential to produce lumber.

The growth variables, DBH and MAI showed significant and positive correlations in relation to LRS.

The evaluation of the LRS and growth variables in canafistula trees older than those analyzed is recommended.

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