

Evaluation of longitudinal residual strain  
of *Eucalyptus saligna* Smith. woodAvaliação das deformações residuais longitudinais  
da madeira de *Eucalyptus saligna* Smith.Rafael Beltrame<sup>1</sup>, Bruno Dufau Mattos<sup>2</sup>, Clovis Roberto Haselein<sup>3</sup>, Elio Jose Santini<sup>3</sup>,  
Darci Alberto Gatto<sup>1</sup>, Pedro Henrique Gonzalez de Cademartori<sup>4</sup> e Cristiane Pedrazzi<sup>1</sup>**Abstract**

The present study was done in order to determine the longitudinal residual strain (LRS) from growth stresses in *Eucalyptus saligna* trees. To achieve this, 120 trees (nine years old) of 12 plots from an experimental population were randomly selected based on their phytosanitary conditions. The basic density, bark thickness, diameter at breast height, volume and total height were measured. The measurements of LRS were performed through a strain gauge (Growth Strain Gauge) by the CIRAD-Fôret non-destructive method in four positions around the stem of tree. The results showed that LRS values were higher than values found in other studies for *Eucalyptus* species. Growth parameters showed significant and positive correlations between themselves but most of these parameters did not correlate to LRS. However, LRS measured in four positions around the stem of the trees showed statistical differences between them. On the one hand, LRS measurements of plots 3 and 7 showed satisfactory results, better distribution around the stem and, consequently, the smallest strains. On the other hand, plots 1 and 6 showed high values of strains and, consequently, a high variation between the positions.

**Keywords:** *Eucalyptus saligna*; growth stress; non-destructive evaluation; wood properties; wood quality.

**Resumo**

O presente estudo foi desenvolvido com o objetivo de determinar as deformações residuais longitudinais, decorrentes das tensões de crescimento em árvores de *Eucalyptus saligna*. Para tanto, foram selecionadas 120 árvores em 12 parcelas de um povoamento experimental com nove anos de idade, por meio de suas condições fitossanitárias. Foram mensuradas as variáveis de densidade básica, espessura de casca, diâmetro a altura do peito e altura total. As leituras das DRLs foram realizadas pelo método não destrutivo CIRAD-Fôret, com o auxílio do extensômetro (Growth Strain Gauge). Estas leituras foram realizadas em quatro posições ao redor do tronco da árvore. De acordo com os resultados obtidos, pôde-se verificar que a DRL média para a espécie estudada, apresentou valores superiores quando comparada com outras espécies de eucalipto reportadas na literatura. As variáveis de crescimento apresentaram correlações significativas e positivas entre si, todavia, a maioria destas variáveis não se correlacionou com as DRLs. Já as quatro posições de leituras realizadas ao redor do tronco das árvores apresentaram diferenças estatísticas entre si. Os níveis de variações das DRLs, das parcelas amostradas 3 e 7, apresentaram resultados satisfatórios com melhores distribuições em torno do tronco, proporcionando as menores deformações. Por outro lado, as parcelas 1 e 6 apresentaram maiores valores desta deformação e, com isso, uma maior variação entre as posições de leituras.

**Palavras-chave:** *Eucalyptus saligna*; tensões de crescimento; avaliações não destrutivas; propriedades da madeira; qualidade da madeira.

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## INTRODUCTION

Determining the best quality of timber is constantly performed in wood industries. However, quality gets compromised due to the difficulty to obtain logs with high diameter and; consequently sawing of logs with small diameter has been more frequently used at industries. Therefore, the presence of boards with many defects, such as knots, juvenile wood and high growth stresses that are responsible for a low yield, is a normal occurrence (CARDOSO JÚNIOR *et al.*, 2007).

According to Trugilho *et al.* (2006), a great potential of *Eucalyptus* wood for noble purposes is associated to the diversity of species and a high capacity to generating clones and hybrids. This diversity enables the use of the *Eucalyptus* genus in genetic improvement programs, forest management and the use of adequate technologies for processing and machine use in order to solve or minimise wood defects such as cracks and warps.

The “Proyecto Fair” of the Centro de Innovación e Servizos da Madera (CIS –MADERA, 2001) states that growth stresses comprehend the group stresses from different origins inside any tree, producing equilibrium along its growth. On the one hand, support stresses have an intuitive character and exist due to the characteristics related to the weight of trees and its canopy architecture, for instance. On the other hand, maturation stresses are produced through a complex process of wood fibre maturation.

The stress related to the weight of trees is not important when compared to the cellular maturation and the term “growth stress” is used to denote only this last one. Growth stresses are originated in cell growth that are responsible for cambium generation. Moreover, these stresses tend to expand sideways and shrink longitudinally during the process of aging. However, these modifications in the structure are suppressed by cells formed in previous years, generating a group of stresses (CIS –MADERA, 2001).

According to Trugilho *et al.* (2004), the problem consists in the way to determine the magnitude of stress. Scientific bibliography presents many possibilities to measure growth stresses. However, each stress limits its utilisation. Moreover, methods of measurement always are based on indirect determination of stresses. The method used at the “Centre de Coopération Internationale em Recherche Agronomique pour le Développement”, Département des Forêts - CIRAD-Forêt (Growth Strain Gauge) is easily employed

and permits a quick data collection as the evaluation is performed in standing trees. This method determines the longitudinal residual strain (LRS) at a fixed distance, which is directly proportional to the growth stress in the longitudinal direction.

Considering these facts, the present study aimed at evaluating the longitudinal residual strain from growth stresses through the CIRAD-Fôret method in *Eucalyptus saligna* Smith wood, as an aid to genetic improvement programs.

## MATERIAL AND METHODS

### Collection site characterisation and trees selection

The material used in this study was from an experimental population located in Eldorado do Sul city (51°37'54" W and 30°7'33" S), state of Rio Grande do Sul, Brazil. The experimental population was planted in September 2000 at 3.0 x 2.7 m spacing in plots with 25 trees for each treatment.

Twelve plots were randomly selected and, for each plot, 10 *Eucalyptus saligna* trees were randomly selected, totalizing 120 trees. The selection of the trees taking into consideration phytosanitary conditions, stem form (rectilinear), absence of bifurcation, phenotype and bordure trees in order to eliminate interference of wind and relief with great slopes.

### Measured parameters

Diameter at breast height (DBH), bark thickness (BT), total height (H), volume (V), basic density (BD) and longitudinal residual strain (LRS) were measured. Diameter at breast height (DBH) was measured around the stem considering the bark through a bevel. The bark thickness (BT) was measured using a machete to remove the bark at breast height (DBH) and a digital calliper. The total height (H) was determined using Vertex III equipment. This equipment has a transponder that is set in the tree in order to measure its height.

The basic density (BD) was measured in standing and alive trees using Pilodyn equipment. This equipment has an easy handling, a fast measure and is destructive only in the test local. The Pilodyn measures the density of tree through stem strength to drilling a drill with diameter of 3 mm and length of 50 mm. This drill penetrates into the stem and records drilling in a scale (0-50 mm). The measuring of basic density was performed with absence of bark at 1.30 m length of the tree.

Longitudinal residual strains (LRS) were evaluated in standing and alive trees using extensometer (Growth Strain Gauge) equipment through the CIRAD-Fôret method. Firstly, the barks of stem trees were removed at DBH height (1.30 m) in order to open a space. Therefore, two pins distanced 45 mm were introduced on direction of the grain in order to fix the equipment. Moreover, a hole with diameter of 20 mm was made between the two pins using a manual drill.

The rupture of wood tissue due to the drill induces liberation of the strains inside of the tree. These strains are recorded through the equipment and correspond to indirect measurement of the growth stresses (Figure 1).

The measurement of LRS was performed in four positions around the stem of the same tree (MUNERI *et al.*, 1999; 2000), in the same order of the planting to standardise the measures. The lines and space between rows were oriented towards the cardinal points. The reading order was according to Table 1.

**Table 1.** Sequences of the measuring of LRS around the tree stem.

**Tabela 1.** Sequência de leituras das deformação residuais longitudinais ao redor do tronco da árvore.

Reading sequence	Reading place	Positions
1°	Planting line	East
2°	Between line of the planting	North
3°	Planting line	West
4°	Between line of the planting	South

The measurement of strains was performed in absence of wind once movement of the tree causes oscillation of the sustenance strength inside of the stem, modifying the values recorded by the equipment.

### Statistical analysis

Data collected of the parameters (LRS, BD, BT, DBH, H, V) and the values of four positions around the stem: line (east), space between rows (north), line (west) and space between rows (south) were analysed through analysis of variance ( $p < 0,05$  and  $p < 0,01$ ). When the null hypothesis was rejected, the average values were compared through LSD Fisher Test at the level of significance of 5%.

## RESULTS AND DISCUSSION

The statistical parameters of longitudinal residual strain, basic density, bark thickness, diameter at breast height, total height and volume the trees of *Eucalyptus saligna* are shown in Table 2.

Table 2 shows that the average value of LRS is higher than found in other studies with *Eucalyptus* spp. trees (TRUGILHO *et al.* 2006; CARDOSO JÚNIOR *et al.* 2007; PÁDUA *et al.* 2004) that evaluated the LRS variations as a function of spacing plot and age of trees. Probably, the studies realised by Cardoso Júnior *et al.* (2007), Pádua *et al.* (2004) and Trugilho *et al.* (2006), showed better results



**Figure 1.** Determination of longitudinal residual strain (LRS): drilling of the stem (a), measurement of the strain through the extensometer (b).

**Figura 1.** Determinação da deformação residual longitudinal (LRS): perfuração do tronco (a), leitura da deformação por meio do extensômetro (b).

**Table 2.** Statistical parameters of the variables.

**Tabela 2.** Parâmetros estatísticos das variáveis.

Parameter	LRS (mm)	BD (kg.m <sup>-3</sup> )	BT (mm)	DBH (cm)	H (m)	V (m <sup>3</sup> )
Average	0.152	493.8	5.698	21.62	31.41	0.488
Deviation	0.056	17.80	2.383	0.805	1.732	0.127
Minimum	0.072	449.6	15.82	3.860	25.10	0.204
Maximum	0.353	530.8	28.33	8.380	35.00	0.889

than the present study, mainly due to genetic improvement of evaluated trees, inasmuch planting age is similar to the planting age of this study.

Trugilho *et al.* (2004) studied the effect of age on the longitudinal residual strains of *Eucalyptus dunnii* trees and reported similar values to found in this study. The authors found 0.107, 0.113, 0.111, 0.123 mm to trees with 8, 13, 15 and 19 years old, respectively.

The results of basic density (DB) obtained through Pilodyn showed similarity to reported by Beltrame (2010), who found average value of 471.96 Kg.m<sup>3</sup> in trees of *Eucalyptus* spp. (9 years old). Furthermore, the author observed higher values (8.05 cm) of bark thickness than found in this study.

Table 3 shows the correlation matrix between the longitudinal residual strain (LRS) and the growth variables of trees.

The correlations values between LRS and growth variables were not significant, except for the parameter BT, which showed a great association to LRS. However, some growth parameters showed significant correlations each other as H, DBH and V.

Significant correlations between LRS and BD were expected, equally found by Trugilho (2005).

However, non-destructive method (Pylodin) used to measure BD in standing and alive *Eucalyptus saligna* trees was unfavorable and, consequently, significant correlations were not verified.

Souza *et al.* (2004) reported similar results to this study. The authors did not verified significant correlations between LRS and growth parameters (DBH, H and average annual increment) to *Eucalyptus* spp. species (6 years old).

On the other hand, Lima *et al.* (2004) found significant correlations between LRS and DBH, stem volume and stability factor for natural hybrids of *Eucalyptus grandis*. However, the authors did not observe significant correlations between LRS and H. Beltrame (2010) stated positive and significant correlation between LRS and BT as well negative and significant correlation between DBH and V to *Eucalyptus* spp. species.

Likewise, Trugilho *et al.* (2007) reported a low influence of growth characteristics on LRS of *Eucalyptus* spp. clones. The differences found in all the studies demonstrate that parameters have different correlations towards the species even being the same genus.

Table 4 shows the results of analysis of variance to LRS according to the four measuring positions around the stems of the trees.

**Table 3.** Pearson correlation matrix between the longitudinal residual strain (LRS), basic density (BD), bark thickness (BT), diameter at breast height (DBH), total height (H) and volume of standing tree (V).

**Tabela 3.** Matriz de correlação de Pearson entre a deformação longitudinal residual (LRS), massa específica básica (BD), espessura da casca (BT), diâmetro a altura do peito (DBH), altura total (H) e volume da árvore em pé (V).

Variables	LRS (mm)	BD (Kg.m <sup>-3</sup> )	BT (mm)	DBH (cm)	H (m)	V (m <sup>3</sup> )
LRS (mm)	1	- 0.1646 <sup>ns</sup>	0.1948*	- 0.1626 <sup>ns</sup>	- 0.1336 <sup>ns</sup>	- 0.1427 <sup>ns</sup>
BD (Kg/m <sup>3</sup> )		1	0.0354 <sup>ns</sup>	0.2612**	0.5483**	0.3144**
BT (mm)			1	0.5497**	0.2969**	0.5147**
DBH (cm)				1	0.6980**	0.9857**
H (m)					1	0.7730**
V (m <sup>3</sup> )						1

\*\* Significant at the level of probability of error of 1%; \* significant at the level of probability of error of 5%; ns not significant.

**Table 4.** Analysis of variance of LRS of *Eucalyptus saligna* according to the four positions around the stem of the tree.

**Tabela 4.** Análise de variância da LRS do *Eucalyptus saligna* em função das quatro posições de leitura ao redor do tronco da árvore.

Source	DF	SS	MS	F	P value
Positions	3	0,05788	0,019293	3,81	0,001
Error	476	2,40963	0,005062		
Total	479	2,46751			

Where: DF = degree of freedom; SS = sum of squares; MS = mean square; F = value of F calculate; Prob.>F = level of probability of error.

LRS presents significant variation around the stems of the trees at the level of significance of 5%. Likewise, Beltrame (2010) also verified the same variation in the measuring positions around the stems of trees for different species of *Eucalyptus* spp.

Melo (2004) reported that variations in the intensity of growth stresses had been detected around the stem, ranging between species and within of the same specie.

Table 5 shows the average values of LRS around the stems of the trees (cardinal points).

**Table 5.** Peripheral distribution of longitudinal residual strain (LRS, in mm) around the stem.

**Tabela 5.** Distribuição periférica da deformação longitudinal residual (LRS, em mm) ao redor do tronco.

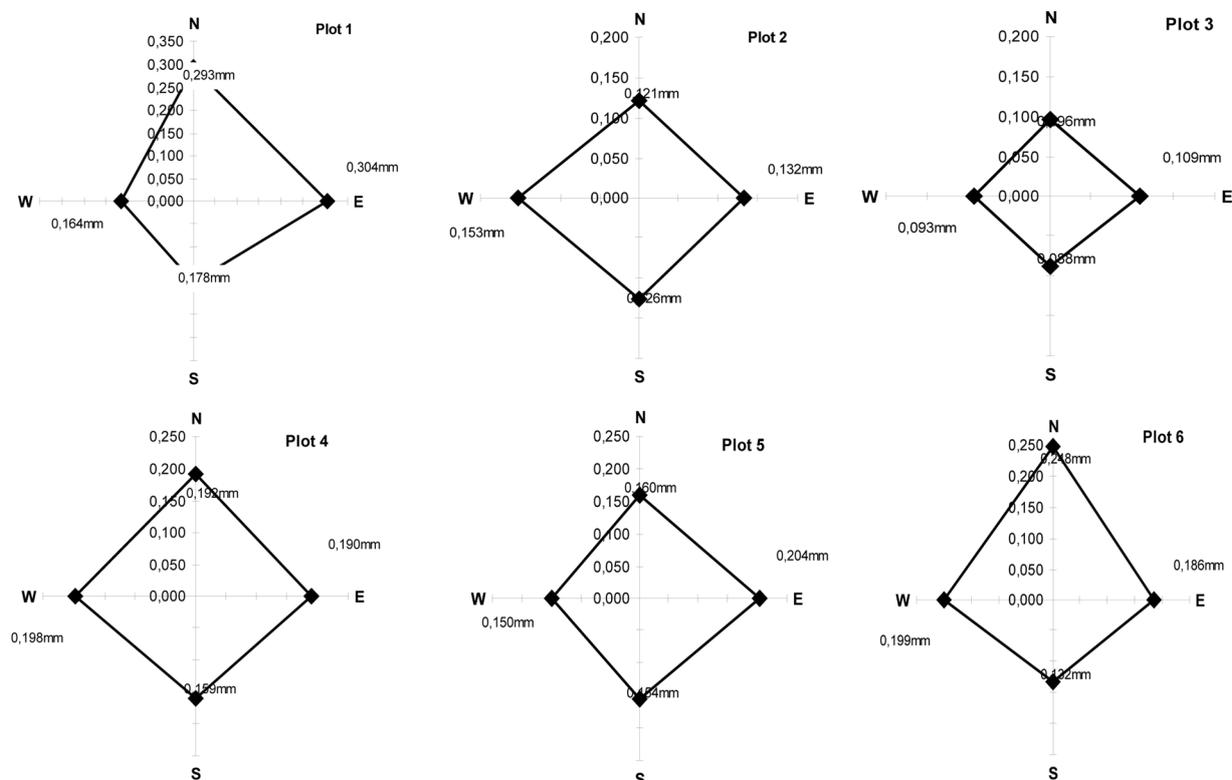
LRS	Number of samples	Average	LSD Fisher
West	120	0,1334	A
East	120	0,1631	B
North	120	0,1542	B
South	120	0,1551	B

Where: LRS = longitudinal residual strain (mm); Averages with the same letter not differ each other at the level of probability of error of 5% (LSD Fisher Test,  $p < 0,05$ ).

The west position presented lowest value of LRS, whereas other positions was not significant. Trugilho *et al.* (2006) reported highest values of LRS in north and south positions and affirmed that those values could be indicating the presence of reaction wood. Equally to this study, Beltrame (2010) observed that the west line position of planting showed the lowest average value of LRS.

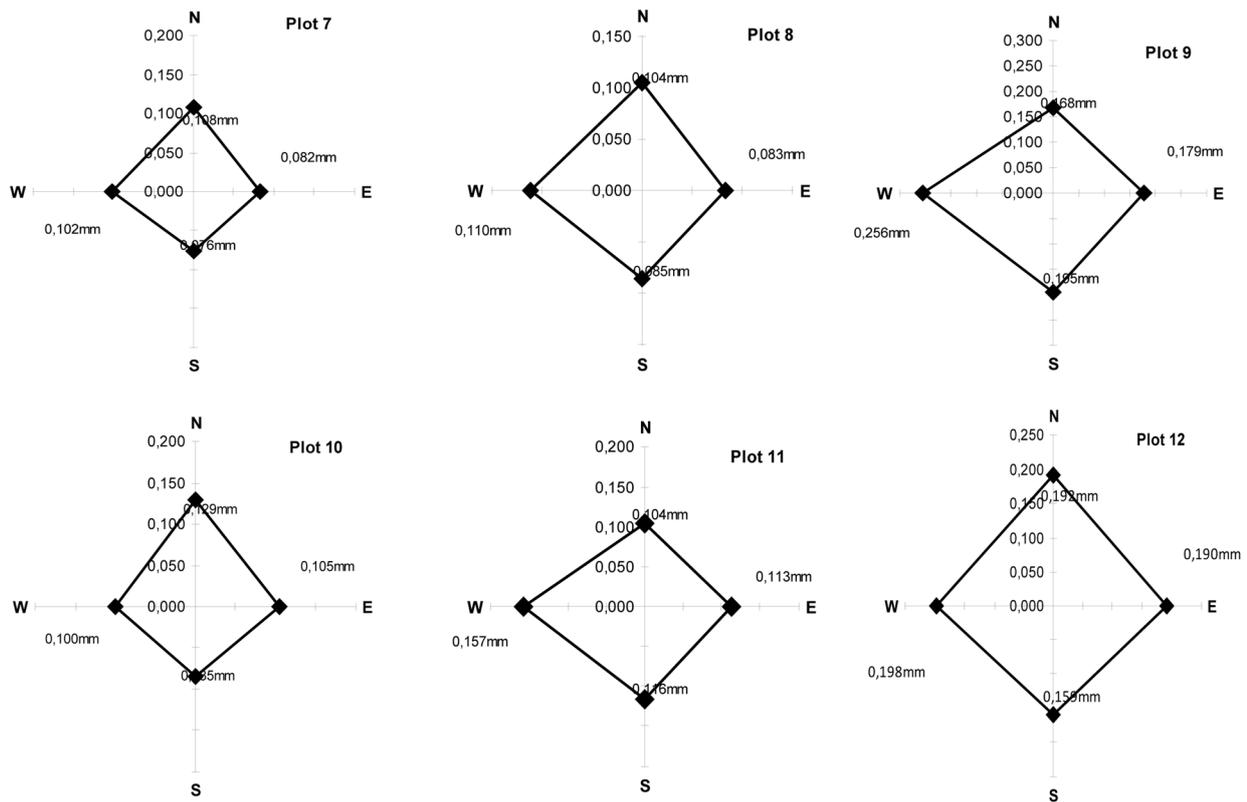
Carvalho *et al.* (2010) stated that *Corymbia citriodora* and *Eucalyptus urophylla* trees presented an individual variation around the stem and some instability along the circumference. The authors affirmed that variation could be attributed to the internal factors such as constitution of juvenile wood. However, according to Schacht *et al.* (1998) the variation of LRS could be associated to environmental factors (effect of competition for light and wind) and factors related to the trees (stem inclination, grain orientation, wood reaction and tortuousness).

Figure 2 presents the variations of LRS around the stem (cardinal points) of the *Eucalyptus saligna* trees in the twelve plots.



**Figure 2.** Distribution of longitudinal residual strain (LRS, in mm) in the four positions of readings around the stem of *Eucalyptus saligna* trees.

**Figura 2.** Distribuição da deformação longitudinal residual (LRS, em mm) para as quatro posições de leitura ao redor do tronco das árvores de *Eucalyptus saligna*.



**Figure 2 - Continuation.** Distribution of longitudinal residual strain (LRS, in mm) in the four positions of readings around the stem of *Eucalyptus saligna* trees.

**Figura 2 - Continuação.** Distribuição da deformação longitudinal residual (LRS, em mm) para as quatro posições de leitura ao redor do tronco das árvores de *Eucalyptus saligna*.

Figure 2 demonstrates that LRS in the plots 3 and 7 showed the best distribution around the stem of the trees and the lowest strains. On the other hand, LRS in the plots 1 and 6 presented high values of strain and consequently a high variation between the measuring positions. Therefore, the best improvement of the material can be performed. The trees with lowest LRS could be used as sawn timber and the trees with highest LRS could be used in industries of cellulose and fibers. Moreover, this separation and characterisation of trees within the same group is useful in order to predict its future behaviour and utilisation in improvement programs for productivity and quality of wood (SANTOS *et al.*, 2006).

## CONCLUSIONS

*Eucalyptus saligna* showed high levels of LRS, which ranges as a function of position around the stem of tree.

The high levels of LRS could be associated to the presence of juvenile wood in the evaluated trees inasmuch the planting is recent. Moreover,

low spacing between the trees is related to fast-growth planting, factor that also influenced the obtainment of high levels of LRS.

If the analyses of LRS will realised considering each plot, a great planning of utilisation of wood will be provide. Thus, plots with low levels of LRS could be used to sawing and plots with high levels of LRS could be used to production of biomass.

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