Growth stress in *Eucalyptus nitens* at different stages of development

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Abstract

Eucalypts are renowned for their high growth stress levels. These stresses cause splitting, warping and dimensional instability when cutting, processing and drying the wood. In Chile, large *Eucalyptus nitens* plantations can be found, which, due these problems, are scarcely utilised for solid wood (veneer, sawn wood). This study aims to determine the factors influencing growth stress at different stages of development, and to identify whether the factors influencing growth stress change over time. In five stands of different ages, growth strain was measured at different tree heights with the single hole drilling method. The tree variables, diameter breast at height (DBH), tree height, slenderness (height/diameter ratio) and crown parameters also were measured. A stepwise regression analysis of tree variables and growth strains was undertaken. The results obtained indicate a high variability in growth strain values. It was concluded that growth strain is not correlated with a single growth parameter, but with a combination of factors that variously influence it at different ages and tree heights.

Keywords: growth stress, growth strain, *Eucalyptus nitens,* stages of development, sawnwood

Introduction

Plantation forestry plays an important role in the economy of Chile. The pulp and paper industry in Chile, on the other hand, is focused on the utilisation of *Eucalyptus globulus* for the production of high quality pulp, which requires only a small percentage of *E.nitens*. As a consequence of the pulp and paper industry's limited interest in *E.nitens,* large areas of older *E.nitens* stands are still present in the southern part of Chile, some of which already have attained sawlog dimensions. Aside from reconstituted wood products, the generation of higher value products such as quality veneer or sawn timber may be an option for the future.
Problems arise when processing and drying trees with high growth stresses. Defects such as log end splitting, distortions, cracks (Fig. 1) and checking are often reported (Archer, 1986; Touza, 2001; Yang and Waugh, 1996; Yao, 1979).

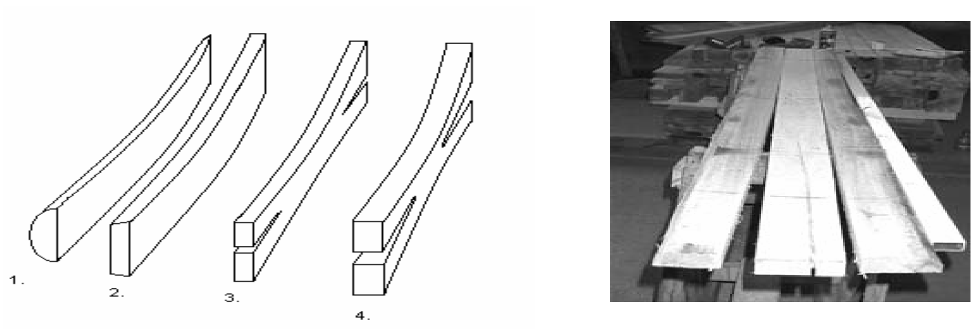

Fig. 1: *Bow and spring (1. and 2.), and end split (3. and 4.) occur frequently during processing of sawlogs with high tensions.*

Thus, an analysis of the potential to reduce growth stress is of major interest if one aims to increase the utilisation of *E.nitens* wood. Several scientific investigations of growth stresses in eucalypts have been conducted. Most have focussed on trees of harvestable size (Lemos, 2002; Touza Vázquez, 2004; Vignote *et al.,* 1996; Wellhöfer, 2001). Although the development of growth stress is a dynamic process, few studies have investigated tree growth stress at different stages of development. The literature suggests that growth parameters such as crown width, crown area, crown eccentricity, crown length, tree height and DBH may influence growth stress. These parameters also describe individual tree competition in stands. Authors' reports about which parameters affect growth stresses to a larger degree are conflicting.
The origin of growth stress has been analysed extensively. Firstly, the maturation of the wood cells causes stress, termed "maturation stress", and, secondly, crown weight and bending as a result of wind cause "supported stress". During the maturation of the newly formed wood, the cells, which grow every year on the stem periphery, contract longitudinally while the lignified wood cells already formed impede this contraction. This causes tension inside the stems, which contributes to the protection of new wood cells from bruising. In keeping with the theory from (Kübler, 1959a), growth stresses are highest at the stem periphery to prevent non-lignified cambium cells becoming compacted in the event that external forces, such as wind, cause young trees to bend. This

theoretical approach says that a tree is in perfect balance when a tension zone, at a maximum close to the bark, and a compression zone in the centre of the tree occur, resulting in a line of zero tension between the two zones at two thirds of the radius (2/3 r) (Fig. 2).

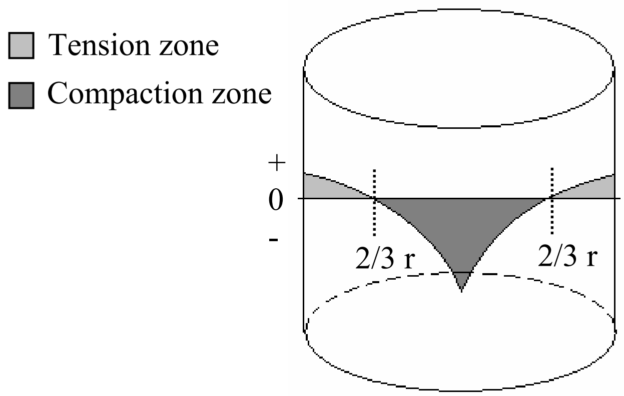

Fig. 2: *Distribution of growth stress in the stem with tension (+ value) and compression (- value) forces in perfect balance according to Kübler's theory (Kübler 1959b).*

Based on this theory, peripheral growth stress is estimated from growth strain release, which, unlike growth stress, can be measured directly with the CIRAD-Forệt growth strain gauge method (Yang and Waugh 2001). Thus the growth strain values may be used as growth stress indicators (GSI). Kübler (1959a) maintains that processing and drying timber from trees with low surficial strains present minimal problems, yet practice proves this untrue in many cases as trees with rather low surficial growth strains do occasionally warp and split. Okuyama (1997) shows that the tension and compression zones in trees rarely are balanced perfectly in their distribution as assumed by (Kübler, 1959a). According to Kübler (1959b), tension wood at the stem periphery is reversible because, with ongoing diameter growth, the "tension zone" becomes a "compression zone" as it graduates to the inner two-thirds of the stem radius. Yet, in some cases, growth stresses are such that tension wood is formed. In this case, the substantial amount tension wood formed results in an irreversible conversion of the cells embedded in the wood tissue. In such cases, Kübler's assumptions are invalid. Therefore, conclusions about real growth stress distribution in the trees drawn from measurements of the peripheral growth strain only may be incorrect.

The semi-destructive nature of gauge measurements prohibits repeated measurement at the one tree height, thereby ruling out the possibility of developing time series of tree growth stress. To assist decisions towards the development of solid wood management programs for the production of sawlogs with minimal growth stress at each stage of development, this study aims to investigate whether a dynamic change in the relationship between growth parameters and growth stress levels over the lifespan of eucalypt trees occurs. To achieve this, the growth tree parameters that may influence growth stress in eucalypts are analysed.

Material and Methods

Material to be analysed

The study is based on the analysis peripheral growth strain measurements from 50 *Eucalyptus nitens* trees from the Pre- Andean zone of the 8th Chilean region. In total, five stands at the ages 3, 7, 9, 10 and 14 years were selected. Each sample plot in a stand consisted of 10 trees with different social positions (5 co-dominant, and 5 dominant or pre-dominant). Homogeneity of the sites and growth conditions was important in the selection of the stands to ensure comparability of data for the different stages of development. Growth strain was measured at 1.3m, and at 25% and 50% of total tree height in the north, south, east and west directions. The relative values at these heights were then compared for trees of different ages.

Measurements of individual tree growth parameters such as crown width, crown area, crown eccentricity, crown length, tree height and DBH, and also slenderness (height/diameter ratio) were taken to correlate growth parameters and growth strain measurements (GSI).

The range in DBH and tree heights spanned 8 to 44 cm and 9 to 45 m respectively. Crown size and crown eccentricity were derived from crown projection area measurements. From tree and crown distribution data, maps were generated with the software program Arc. View© to analyse individual crown competition and its effect on peripheral growth strain.

Method of growth strain detection

Following the procedure developed by Fournier (1994), growth strain measurements were taken with the CIRAD-Forêt growth strain gauge, which detects growth strain at the stem periphery by taking measurements on the stem under the bark. By cutting the fibres between two nails with a drill, stress is released, and the disbanding between the nails is measured in micro metres (µm). The values measured indicate the growth strain on the stem periphery. According to Kübler (1959a), growth strain can be adopted as an indicator of growth stress levels (GSI). The growth strain data obtained were stratified by age class, and evaluated statistically with the software package SAS 9.2©. A stepwise regression analysis was undertaken to obtain relationships between tree growth parameters and growth strain values.

Results

The growth strain values vary significantly over time and at different stem heights (Fig. 3). While mean growth strain at 1.30m height was moderate in the youngest trees, it increased with age to 10 years when the trees reach heights of about 35m. At age 14, when trees achieved sawlog dimensions, the GSI is significantly lower. Such a trend was not found for the GSI at the upper height of trees aged 7 to 10 years. Then, stress levels remained more or less constant. Up to age 10 years, the GSI values were always highest at 1.3m height. The mean values of the maximum growth strain for each height and age class indicated that, between 7 and 10 years of age, trees were prone to tension wood formation.

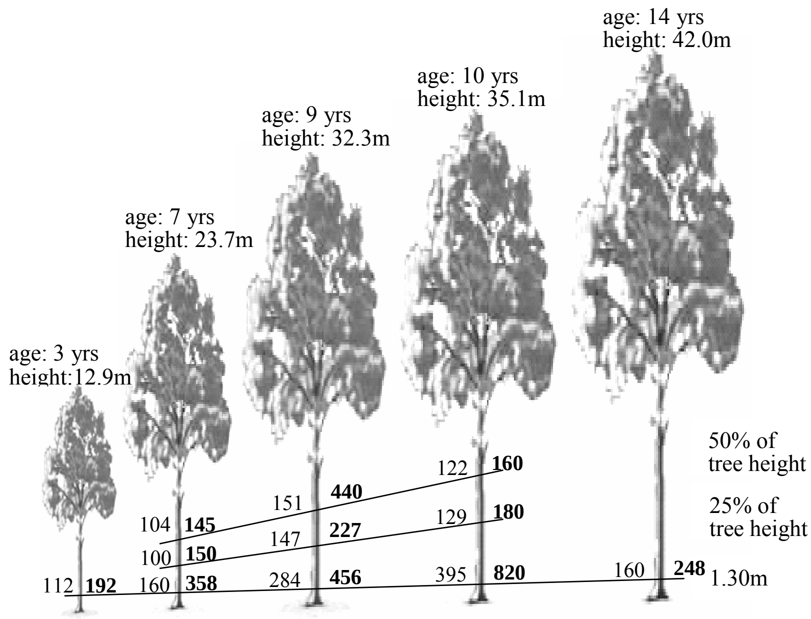

Fig. 3: *Growth strains (GSI=growth stress indicators; change in microns) measured for 5 age classes, and at 3 stem heights: the numbers on the left of the tree indicate mean GSI-value (average of 4 measurements); the bold numbers on the right give the average maximum values at each tree height.*

Growth strain influencing factors over time and stem height

In a next step a stepwise regression analysis using age as a classifying variable was conducted (Table 1). The statistical relation among tree variables and GSI at different stem heights was examined and those variables selected which show significance level of $p<0.10$.
It can be shown that at different ages and different tree heights the GSI influencing variables change. A very common influencing factor entering in the regression models of younger trees is crown eccentricity and variables related to tree height.

Age	**GSI 1,3 mean**	**R^2**	**GSI 1,3 max**	**R^2**
3	h/d (R^2=0,35), cd (R^2=0,40), CCG_D (R^2=0,03)	***0.78***	h/d (R^2=0,34), CCG_E (R^2=0,25)	***0.59***
7	CCG_D	***0.36***	X	***X***
9	CCG_E	***0.39***	CCG_E	***0.55***
10	height	***0.42***	Hdom_p	***0.41***
14	Hdom_p	***0.45***	Hdom_p	***0.39***
	GSI 25 mean	**R^2**	**GSI 25 max**	**R^2**
7	CCG_E	***0.47***	CCG_D (R^2=0,42), cd (R^2=0,33)	***0.75***
9	Height (R^2=0,30), DBH (R^2=0,31)	***0.61***	height	***0.38***
10	height	***0.45***	Cd (R^2=0,45), h/d(R^2=0,15)	***0.60***
	GSI 50 mean	**R^2**	**GSI 50 max**	**R^2**
7	CCG_E	***0.45***	CCG_E	***0.60***
9	X	***X***	X	***X***
10	cd	***0.44***	cd	***0.40***

Table 1: Results of the stepwise regression analysis (p<0.1),
GSI 1,3 mean/max = mean/max Growth stress indicator values at 1,3 m stem height
GSI 25 mean/max = mean/max Growth stress indicator values at 25% of tree height
GSI 50 mean/max = mean/max Growth stress indicator values at 50% of tree height
DBH = diameter at 1.3m stem height, H/D = height/diameter ratio, CD = crown diameter, height = tree height; H_dom_p = dominant height of 100 thickest trees/ha, CCG_D=direction of crown center of gravity, CCG_E = distance from center of crown gravity, X=no variable found within 0.1 significance

By means of the coefficient of determination (R^2) the influence of tree parameters on growth strain can be estimated. Due to the stratification after age the number of observations in each age class is low. To confirm the results further research with a higher number of observations is necessary. Although the trends are consistent, no general model valid for all ages and competition situations can be found. Further analysis and development of competition describing variables are necessary. Unfortunately no growth strain measurements above 1.3m stem height could be taken in the 3- and 14-year-old stands. Clearly, the stepwise regression results show that growth strain is influenced by different tree parameters throughout different stages of development.

Discussion

The coefficient of determination (R^2) between growth parameters and peripheral growth strain values (GSI) are rather low. But it shows that multiple parameters affect growth strains. Nutto and Touza Vázquez (2005) came to the same conclusion in their investigations of different-aged *E. globulus*. Their results indicate the importance of the stage of development when determining the influence of tree parameters on growth strain.

The objective of the study was to identify tree growth parameters influencing growth strain to avoid the formation of tension wood during a rotation. This would be achieved by adopting silvicultural approaches that help minimise growth stresses. The results show that, in very young stands (age 3 years), slenderness is the most important factor for keeping growth strains low. To reduce the ratio of tree diameter to tree height, a wider spacing can be chosen to reduce the competition among trees, creating more growing space and thereby enhancing diameter increment. In the stands at age 7 years, the influential growth parameters have changed already. Crown symmetry has become the most important factor for keeping growth strains low. This is true for growth strains measured at all stem heights. At height 1.3m, the maximum GSI values are already very high, at which point symmetric crown development becomes a priority. At this stage of development, tree spacing and thinning should enable trees to form symmetrical crowns to achieve homogeneous competition conditions.

For the 9-year-old stands, growth strain at 1.3m still is most influenced by crown symmetry. For the upper heights in these stands, as well as for the 10-year-old trees, tree height and social position of the tree become more important. Dominant trees are more likely affected by their higher exposure to wind, which causes crown surface roughness. However, this stage is crucial for the wood quality as undesirable tension wood may be formed. At 1.3m height, the GSI values can reach critical levels. As a consequence, moderate thinnings should be implemented to produce more homogeneous conditions.

For the 14-year-old stand, the parameters, measured at tree heights of 1.3m, that influence growth strain are similar to those for 10-year-old trees but the growth strain levels are significantly lower than for younger stands. The focus should be placed on less dominant trees because of their lower growth stress levels. This contradicts many studies presented in the literature, in which a tendency towards lower growth strains with decreasing competition is described, i.e., for the dominant trees (Cardoso Junior et al., 2005; Ferrand, 1982; Saurat and Gueneau, 1976). Most of the studies were carried out in stands comprising trees with harvestable dimensions (Lemos, 2002; Touza Vázquez, 2004; Valdes 2004; Vignote *et al.,* 1996; Wellhöfer, 2001). It is often stated in the literature that age is important because growth strains decrease as trees age. Other investigations showed (Nutto and Touza Vázquez, 2005), at least for *E. globulus*, that growth strain levels in fact decrease at 1.3m height, but that growth stress level may increase dramatically at upper stem heights. This was confirmed by other studies of different eucalypt species and beech (*Fagus sylvatica*) (Beimgraben, 2002; Bleile, 2006; Lemos, 2002; Raymond et al., 2002). The study represents the first attempt to obtain more detailed information about the dynamic of growth strains at the stem periphery at different stages of tree development. As only a limited number of trees were available, the results will need to be confirmed by further research.

Conclusions

The stepwise regression analysis shows a multiplicity of factors influencing growth strain in *E.nitens* trees at different stages of development. At different development stages, the parameters influencing growth strain in the stem change in the longitudinal and radial direction. Further growth stress investigations of *E.nitens* in stands of different ages are required to support or contradict the conclusions of this study, which have been made after sampling 50 trees, and are therefore only preliminary. Nevertheless the results show that more than one parameter influences growth stress. In the literature, most investigations of factors influencing growth stress are restricted to one stage of development. In this study, we found that the parameters affecting growth strain differ markedly at different stages of development. Therefore, multiple parameters should be considered for the important stages of development to avoid the production of irreversible tension wood cells inside the stem of younger trees, which ultimately can cause warping and splitting of sawlogs. Therefore silvicultural prescriptions that maintain a reduced growth stress levels by managing the relevant tree parameters can lead to lower internal stem growth stress levels, and facilitate a higher utilization of eucalypt round wood.

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