Screening eucalypts for growth-strain

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Introduction

Eucalypt species are fast-growing and can produce high quality timber for appearance and structural products including Laminated Veneer Lumber (LVL). Eucalypts can contain large growth-strains which are associated with log splitting, warp, collapse and brittleheart. These impose substantial costs on processing (Yamamoto 2007). Costly, and only partially effective, mitigation strategies have been developed to reduce wood defects induced by growth-strain. As growth-strain is highly heritable, an alternative approach is to select and grow individuals which display low growth-strain. Until now measurement of growth-strain has been difficult, time consuming and expensive, preventing the assessment of the large number of trees needed by a breeding programme (Altaner 2015). As an example, the largest sample number in any reported growth-strain study was smaller than 230 trees (Solorzano Naranjo 2011). Traditionally selections are made when trees are older, not only increasing costs (e.g. trial management, sample handling) but also substantially extending the breeding cycle and delaying the deployment of improved germplasm (Altaner 2015). Developments at the University of Canterbury have resulted in a unique growth-strain measurement method supported by theoretical analysis (Entwistle 2014) - dubbed the “Splitting” test. It allows for rapid growth-strain assessment on young trees (Chauhan 2010).

Methods

The development of the splitting test, based on the pairing test (Chauhan 2010), has resulted in a simple and quick method of growth-strain measurement which can be used on small stems. The test relies on the release of stored strain energy in a single plane via cutting through the pith as can be seen in Fig. 1. Chauhan (2010) derived Equation 1 to estimate the deflection given growth-strain from the sample geometry.

$$Y_u = \frac{0.87\varepsilon L^2}{R_{avg}} \qquad (1)$$

Where: Y_u is the deflection, ε is the strain, L is the cut length and R_{avg} is the cross-section radius.

Fig. 1: Sample after the "Splitting" test has been performed. The opening is measured and used for the strain calculation along with diameter and cut length. This sample shows significant growth-strain as can be seen from the wide opening.

Data analysis was conducted in R (R Core Team 2015) and JAGS (Plummer 2015), utilizing a Bayesian approach to estimate the heritability of growth-strain at the family level. The effect of coppicing is included as a fixed effect. Specimen groups were grown during different time periods and for different rotation lengths, group is included as a random effect.

The “Splitting” test is physically constrained to positive values, as the opening cannot be reduced in the presence of compression at the stem surface and tension at the pith resulting in left censored data. Bayesian frameworks provide the ability to simulate partially observable data, and therefore reducing the systematic errors which occur due to left censoring. Here the left-censored initial values are sampled from a uniform distribution between -1.5 and 0.

Results and Discussion

This scoping study was substantially larger than any preceding investigations, assessing growth-strain and other wood properties on more than 600 *Eucalyptus bosistoana* and other eucalypt species at an early age (less than 2 years old). The results from these trials showed that growth-strain is heritable, and family rankings varied little whether grown from seed or coppiced from existing root systems. Tab. 1 shows the family mean Spearman rank coefficients of the tested wood properties whether grown from seed or coppice. Fig. 2 shows 20 families (8 half-sib replicates each) ordered by median growth-strain. The family rankings were similar (Spearman coefficient of ~0.77). In particular the top 3rd of the families, i.e. those with the lowest growth-strain were the best in both trials (Fig. 2). Growth-strain increased after coppicing. When plants are coppiced from existing root systems they emerge from the side of the old trunk resulting in a hockey-stick shaped lower stem. Given the nature of the testing procedure, it is suspected that the increase in growth-strain with coppicing was due to the formation of tension wood rather than an indicator that older trees will possess significantly higher growth-strain. Analysis revealed a narrow sense heritability (h^2) of 0.44 with a 95% credible interval of the posterior distribution from 0.20 to 0.67. Tab. 2 shows the h^2 values for the tested wood properties.

Tab 1: Spearman rank coefficients between the family means when grown from seed or coppiced from the existing root systems. Family mean growth-strain rank shows a strong relationship before and after coppicing (~200 plants from seed and ~200 from coppice).

Property	Spearman coefficient
Diameter	0.44
Dry density	0.30
Acoustic velocity	0.69
Stiffness	0.44
Growth-strain	0.77

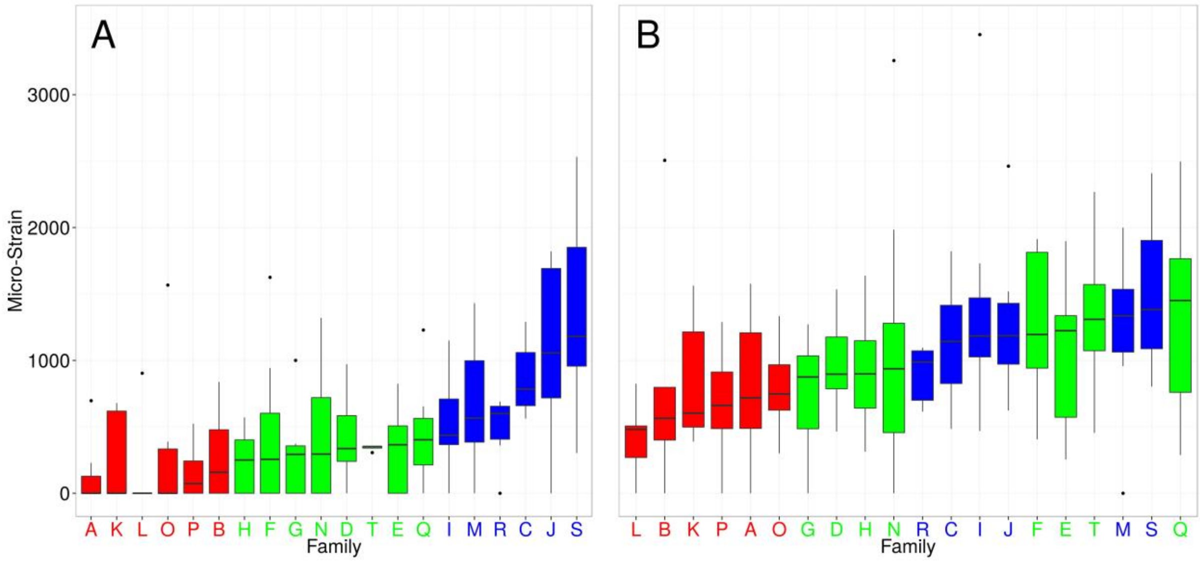

Fig. 2: High (blue), medium (green) and low (red) growth-strain families grown from seed **A** and the same individuals grown from coppice **B**. Note the large number of trees in the low growth-strain families showing closure (zero) during the splitting test and the higher magnitudes of growth-strain when grown form coppice (~200 plants from seed and ~200 from coppice).

Tab. 2: Narrow sense heritability of the measured wood properties. Large credible intervals are present on all heritability estimates, emphasising the need for large sample sizes. Growth-strain is under substantial genetic control (~400 plants from seed and ~200 from coppice).

Property	Heritability	95% Credible Interval
Diameter	0.27	0.087 - 0.46
Dry density	0.45	0.23 – 0.67
Acoustic velocity	0.84	0.54 - 1.14
Stiffness	0.38	0.14 - 0.62
Growth-strain	0.44	0.20 - 0.67

Tab. 3 shows the correlations between the family means of the measured wood properties while Tab. 4 shows the correlations at an individual tree level. The analysis included trees grown from seed and coppice. Acoustic velocity showed a good correlation with growth-strain at the family level but was only moderate at the individual tree level. Dry density showed moderate negative correlations with growth-strain. Diameter showed poor correlations with wood properties. All predictors were less strongly correlated with trees grown from coppice than trees grown from seed (data not shown). Testing for all of these properties can be conducted in less than five minutes per sample at trees as young as one year old. This for the first time allows a sizable wood quality improvement programme at reasonable cost.

Tab 3: Pearson correlation coefficients between family mean wood properties. The results indicated that growth-strain correlated most strongly with acoustic velocity (~200 plants from seed and ~200 from coppice).

	Dry density	Acoustic velocity	Stiffness	Growth-strain
Diameter	-0.09	-0.40	0.26	0.34
Dry density		-0.19	0.45	-0.39
Acoustic velocity			0.75	0.86
Stiffness				0.46

Tab. 4: Pearson correlation coefficients between measured wood properties at the individual tree level. The results indicated growth-strain correlated most strongly with acoustic velocity (~200 plants from seed and ~200 from coppice).

	Dry density	Acoustic velocity	Stiffness	Growth-strain
Diameter	0.33	-0.15	0.33	-0.03
Dry density		-0.55	0.96	-0.45
Acoustic velocity			-0.36	0.59
Stiffness				-0.34

Over the last decade, the New Zealand Drylands Forest Initiative (NZDFI) has obtained the largest collection of seed in the world for a number of naturally durable eucalypt species, including *E. bosistoana*, with the aim of establishing a fast-growing, naturally durable, super-stiff, sustainable plantation timber resource in New Zealand. The basis is a breeding programme which gives wood properties the same priority as growth, form and tree health. This novel approach to tree improvement also includes very early screening (age 1-2) to ensure a timely deployment of improved germplasm (Altaner 2015). With the "Splitting" test, screening of the entire genetic stock is now a practical solution to remove growth-strain induced wood defects. A 10,000 tree trial consisting of ~200 families each with 50 half-sibling replicates of *E. bosistoana* has been established. The trial will be harvested at an age between 18 and 24 months (late 2016 - 2017) and evaluated for growth-strain, as well as improved for early form, growth, stiffness, volumetric shrinkage and basic density. As the tests are destructive the superior individuals need to be rescued by coppicing. Propagation of coppice cuttings is also providing a fast route to deploy improved material to the forestry sector. Additionally, a number of long-term field trials have been established (as early as 2009) throughout New Zealand to provide longer term studies of wood properties in particular heartwood formation.

Due to the nature of the “Splitting” test, strains which result in the closure of the specimen cannot be measured, and as a result are recorded as zero. Fig. 2 shows a number of individuals exhibited closing, particularly when grown from seed, indicating an atypical stress pattern in the stem (Dawson 2011) with greater contraction at the pith than the periphery. The inverted stress-profile may be a result of tension wood being formed by the trees at young age (i.e. at the centre of the stem) to straighten the stem followed by normal wood with lower axial tensile growth-stresses at the periphery. Trees can form reaction wood in response to wind loading (Coutts 1995). A closing sample may indicate increased sensitivity to wind loading and the development of reaction wood at a young age in that genotype. In order to better understand the mechanisms for this unusual behaviour, a new trial has been established in which initial bending will be induced in the stems at a young age followed by straightening.

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