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**Original article**

# Ranking larch genotypes with the Rigidimeter: relationships between modulus of elasticity of standing trees and of sawn timber

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**modulus of elasticity /**
**larch /**
***Larix* /**
**wood stiffness**

**Abstract**

- Direct assessment of modulus of elasticity (MOE) on standing trees is attractive for breeders to evaluate genotypes prior to selection: this can be done using the Rigidimeter, a bending-based measurement device.
- In this study, we tested its reliability to properly rank genotypes by relating trunk MOE with MOEs estimated with a vibrating analysis system (Bing) on different types of conditioned wood specimens from the same trees (boards and standardised $2 \times 2 \times 30$ cm-clear-wood specimens). One hundred and ten trees from different genotypes of hybrid larch (*Larix x eurolepis*) were tested.
- Mean trunk MOE was 7 300 MPa with a similar value obtained for sawn boards. Clear-wood specimens MOE increased from pith to bark from less than 6 000 MPa to nearly 9 000 MPa. Moderate correlations ($r = 0.48-0.61$) were found at the individual tree level between trunk MOE and MOE of wood samples.
- Single specimen MOE was shown to be strongly related to a linear combination of trunk MOE and sample position.
- At the genotype mean level, trunk MOE was highly correlated with wood samples MOE ($r = 0.80-0.91$). Ranking of genotypes based on trunk MOE was mostly consistent with that based on standardised specimens.
- It was concluded that besides other operational advantages which are discussed, the Rigidimeter is a valuable tool for breeders to routinely evaluate and rank genotypes for stiffness prior to further selection.

**Mots-clés :**
**module d'élasticité /**
**mélèze /**
***Larix* /**
**rigidité du bois**

**Résumé – Efficacité du Rigidimètre pour la mesure en routine du module d'élasticité des arbres sur pied.**

- L'évaluation directe du module d'élasticité (MOE) sur arbre debout intéresse les améliorateurs pour l'évaluation de la valeur des génotypes avant sélection : le Rigidimètre permet cette mesure sur arbre debout grâce à une mesure de la déviation du tronc sous l'effet d'une contrainte connue.
- Dans cette étude, nous avons testé sa fiabilité en comparant ce module avec celui obtenu sur divers échantillons de bois séchés, grâce à un système d'analyse vibratoire (Bing). Cent dix arbres, issus d'un test de descendances de mélèze hybride (*Larix x eurolepis*), ont été analysés. Les pièces de bois comprenaient pour chaque arbre : (i) une planche centrale brute (4 cm d'épaisseur et 80 cm de longueur) tirée du billon de pied, (ii) la même planche délignée, et (iii) des éprouvettes standardisées ($2 \times 2 \times 30$ cm).
- Le module de tronc sur pied atteignait en moyenne 7 300 MPa (2 180–12 174 MPa) avec une amplitude au niveau familial de 5 052 MPa à 8 948 MPa. Le MOE des planches était légèrement plus faible (7 256–7 182 MPa). Celui des éprouvettes normalisées variait de moins de 6 000 MPa au niveau de la moëlle à 9 000 MPa vers l'écorce. Des corrélations modérées (0,48–0,61) ont été trouvées au niveau individuel entre MOE sur arbre debout et MOE des échantillons de bois.
- Cependant, il semble possible d'estimer le module des éprouvettes normalisées à partir entre autre du module des arbres sur pied et de la position de l'échantillon dans l'arbre.
- Au niveau génotypique, le module de tronc était très fortement corrélé aux MOE des échantillons (0,80–0,91) et le classement des génotypes est apparu fiable.
- Outre ses autres avantages (e.g. mise en place rapide, évaluation non destructive), le Rigidimètre est donc un outil bien adapté aux besoins des améliorateurs pour évaluer et classer leurs génotypes pour leur rigidité.

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## 1. INTRODUCTION

Among selection criteria, wood properties and in particular wood mechanical parameters are becoming of increasing importance in forest tree breeding programmes. This is particularly true for larch (*Larix* spp.). Indeed on the one hand, larch wood is mostly used in Europe for construction where strength and stiffness are searched for and on the other hand, the wood resource in larch has now extended well-beyond its native mountainous range across European lowlands. These commonly milder new environments together with a more intensive silviculture are usually much more favourable for growth (Pâques, 2002). Growth is even further enhanced by the use in reforestation of fast-growing improved varieties such as hybrid ones (*Larix x eurolepis*). In this context, rotation age is commonly reduced: as consequence, the proportion of juvenile wood is increased as well as the average ring width all over the growing process. The possible negative impact of vigour on wood quality traits is thus a concern for tree breeders.

Wood quality traits useful in breeding programmes will be those for which populations exhibit a large enough genetic variability and a high level of heritability. In addition, for tree breeders, the integration of wood properties as selection criteria relies on at least 3 conditions: (i) the need to assess a large number of genotypes and trees per genotype (several hundreds to several thousands) in order to reliably estimate genetic parameters, (ii) the possibility to reliably assess wood traits as early as possible in order to accelerate breeding cycles and finally, (iii) the need to keep trees alive in experimentation for further additional observations.

In this particular context, many methodological studies have searched for non-destructive, simple and low-cost methodology for routine wood properties determination either on small wood samples such as increment cores or directly on standing trees. Wood density has probably been the most studied property because of its good link with several other major wood properties. Its indirect assessment with tools like the pilodyn, torsiometer and resistograph proved efficient (e.g. Isik and Li, 2003; Nicholls, 1985) because of its good link with wood hardiness. Yet, several authors have also attempted to get access in the same way to other wood properties closer to final use requirements such as wood stiffness (Jacques et al., 2004; Kumar, 2004).

Technologies have been developed to assess wood stiffness on logs or on standing trees. The Grindosonic and Bing devices are commonly used to measure MOE on boards. They are not generally used on logs and cannot be used on standing trees. Tools used on logs such as the HM-200 (Fibre-gen, New Zealand) generally calculate dynamic MOE from measurement of longitudinal resonant frequency, rather than the flexural resonant frequency. On standing trees, MOE can be estimated from a stress wave velocity measurement made using the time of flight approach. Tools used on standing trees include the Fakopp, ST-300, and IML Hammer. Both types of instruments employ stress-waves, as opposed to ultrasound waves. The other technology relies on deflection-based measurements.

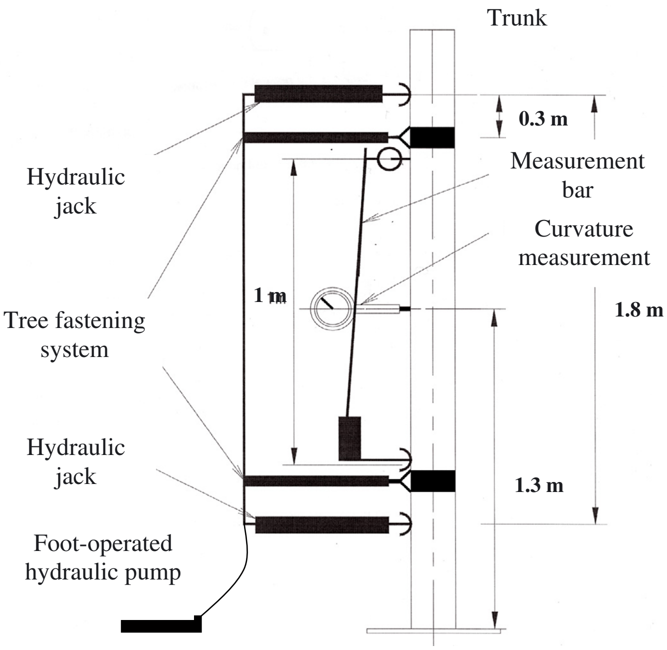

**Figure 1.** Characteristics of the Rigidimeter.

Based on this latter methodology, Launay et al. (2000; 2002) has developed a device called 'Rigidimeter'. It was inspired by Koizumi and Ueda (1986)'s tree bending equipment and benefited from several progressive improvements concerning both its handling and its reliability. At the opposite of the latter, the Rigidimeter allows MOE measurements either on standing trees or on logs. A brief description of the latest device is given below.

The Rigidimeter is made up of two independent units (Fig. 1). The first one is a trunk-bending mechanism, while the second measures the resulting deflection. The centre of the device is generally placed 1.3 m above the ground. The diameter of the trunk is measured at the same height with an accuracy of 0.5 mm. The bending force is applied by way of a rectangular aluminum beam. The rigidity of the pressure bar is calculated in order to prevent deformation during the measurements. The device is fastened onto the trunk, with connections to bark smoothly secured using two wide steel contacts located on both ends of the gantry.

The pressure is generated by a foot-operated hydraulic pump and applied on two points on the trunk via hydraulic jacks. The pressure is directly measured by a digital sensor used to fine-tune the bending forces with an accuracy of 10 N. The mean curvature of the trunk is then measured 1.3 m above the ground level by the second unit. A distance-measurement equipment is gently kept in contact with the trunk by mean of a weight located at the bottom of a leaning bar. The deformation of the trunk produced by the device is detected and measured with an accuracy of 10 μm. In addition, this device was conceived to be light (less than 18 kg) and easily handled (e.g. fastly tied on the tree, rapid loading) so to allow routine assessment of MOE such as needed in breeding programmes (Launay et al., 2000; 2002).

**Table I.** Mean characteristics of trees sampled in the different genotypes.

| | Total height (m) | | | | Breast height (1.30 m) diameter (cm) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Min | Max | Mean | SD | Min | Max |
| F0001 | 11.8 | 1.0 | 9.5 | 13.1 | 17.7 | 2.2 | 14.5 | 20.3 |
| F0161 | 13.1 | 0.8 | 11.7 | 14.4 | 17.8 | 2.2 | 13.1 | 21.0 |
| F0177 | 14.2 | 1.2 | 12.3 | 16.3 | 19.2 | 1.8 | 16.3 | 21.4 |
| F0179 | 15.0 | 1.0 | 12.9 | 16.2 | 19.8 | 0.9 | 18.5 | 21.1 |
| F0180 | 14.0 | 1.3 | 12.1 | 16.2 | 17.4 | 2.0 | 15.1 | 21.2 |
| F0181 | 14.8 | 0.6 | 13.8 | 15.5 | 18.3 | 0.9 | 16.9 | 19.7 |
| F0182 | 14.9 | 1.1 | 12.9 | 16.4 | 19.2 | 0.9 | 17.6 | 20.6 |
| F0183 | 14.7 | 1.1 | 13.0 | 16.4 | 19.0 | 1.4 | 16.0 | 20.9 |
| F0191 | 13.4 | 2.2 | 8.1 | 16.0 | 17.2 | 2.5 | 14.3 | 21.3 |
| F0196 | 14.7 | 1.4 | 12.1 | 16.6 | 18.9 | 1.5 | 16.1 | 20.8 |
| VER1 | 12.5 | 1.2 | 10.6 | 13.9 | 15.7 | 1.4 | 12.6 | 17.0 |

In this study, we have attempted to assess the reliability of the Rigidimeter to estimate modulus of elasticity (MOE) and to validate its interest for routine evaluation such as ranking genotypes in breeding programmes.

## 2. MATERIAL AND METHODS

### 2.1. Measurements and data

Trees used for this study were grown in a hybrid larch progeny trial located in France at Beaumont-du-Lac (West side of Massif Central Mountain range); they were planted in spring 1985 as 2 yr-old bare-root seedlings. They belong to ten European × Japanese larch full-sib families and to one commercial provenance of Japanese larch (VER1) from Hokkaido.

In December 1998, bending tests were conducted with the Rigidimeter. Ten trees per genotype (that is 110 trees in total) were chosen across the trial (Incomplete Randomized Block design with single-tree plots) around the breast height (1.3 m) diameter means of each genotype. Dendrometrical characteristics of these trees are provided in Table I. Mean tree height reached 13.9 m (with a tree range from 8.1 to 16.6 m) and BH diameter: 18.2 cm (range from 12.5 to 21.4 cm).

On each tree, the device was centred at around 1.30 m above the ground level and applied on the southern side of trees. When trunks were too heavily crooked, the orientation was changed. According to tree size, a loading force ranging in-between 4 000 and 5 000 N was applied and the stem deformation (deflection) was then precisely measured. The force was then released to let the tree come back to its original position. The process was repeated 3 additional times, after complete unloading of the Rigidimeter and re-loading. Finally, 2 orthogonal stem diameters over bark were recorded at the level of determination of the curvature deformation.

Diameters were averaged and the trunk MOE was estimated following Launay et al. (2000) as:

$$MOE = (64RFa)/(\pi D^4)$$

with $MOE$ = modulus of elasticity (MPa),

$F$ = force applied to the tree (N),

$a$ = distance between the fixation system to the tree and the extremity of the Rigidimeter (300 mm),

$D$ = tree diameter (mm),

$R$ = radius of curvature of the trunk under flexure (mm); it is a function of $L$, the length of the measurement bar (100 mm) and of $d$ = the stem deformation (mm).

Trunk MOE was averaged over the last three (out of 4) replicates obtained per tree as suggested by Launay et al. (2000).

In August 2000, trees were felled and one 80 cm-long log was cut from each tree, centred at around 1.3 m from the ground to avoid stump effects. The north direction was drawn. A few months later, a 4 cm-thick board (N-S direction) was sawn passing through the pith and left to dry in a store-house and then at laboratory room conditions (average temperature: 20 °C, average RH: 65%). In Fall 2003, modulus of elasticity of each board was measured by a vibrating analysis system called the Bing system, described and validated by Baillères et al. (1998) and Brancheriau and Baillères (2002). MOE was first measured on unedged boards and then on edged rectangular boards. Finally, in each board as many as possible standard 2 × 2 × 30 cm-wood specimens (945 in total) were prepared across the heartwood and sapwood and major visible wood defects (knots, resin pockets, splits, etc) were avoided. Specimens were then conditioned to a 12%-moisture content before further measurements. MOE of specimens was assessed with the same methodology as for boards using the Bing system.

### 2.2. Statistical analysis

The influence of stem diameter on trunk MOE was first tested using diameter as a covariable in a preliminary analysis of variance on genotypes.

Pearson correlations were then computed at the individual tree level between trunk MOE and MOE of boards (unedged and edged) and of standard clear-wood specimens. For the latter, we have separately considered the average MOE of outermost (north and south) specimens, the average MOE of innermost specimens (avoiding the pith) and the average MOE of all specimens across the board (up to 12).

**Table II.** Analysis of covariance for trunk MOE.

| | $df$ | $MS$ | $F$ | $p$-value |
|---|---|---|---|---|
| Genotype | 10 | $12\,008\ 10^3$ | 6.188 | < 0.0001 |
| Diameter covariable | 1 | 196 290 | 0.101 | 0.751 |
| Residual | 95 | 1 940 533 | | |

To assess interest of trunk MOE and thus of the Rigidimeter for breeders, it is also worth to work at the genotype mean level and in particular to check how well the Rigidimeter allows a proper ranking of genotypes, coherent with standard specimens MOE.

The relationships between specimen MOE and trunk MOE, specimen position along the radius, breast height diameter, total height of trees and genotype were studied using univariate and multivariate linear regression analysis conducted using the *R*-statistical package (R Development Core Team, 2006).

## 3. RESULTS

The influence of the breast height diameter on trunk MOEs was first tested and it revealed to be weak and negligible for the rest of the analysis. At the individual tree level, no significant correlation was found between diameter and MOE ($r = 0.108$, $p = 0.510$). As well, while the analysis of covariance showed highly significant differences among genotypes; the use of breast height diameter as a covariable did not improve the precision of the model (Tab. II).

### 3.1. MOE at the individual tree level

Trunk MOE reached on average 7 300 MPa ($CV = 23\%$), with a minimum value of 2 180 MPa and a maximum value of 12 174 MPa.

MOE of unedged boards reached about the same value as for trunk MOE (mean = 7 256) but with a narrower range (3 679 up to 9 369 MPa) and a smaller coefficient of variation (15%). Statistical parameters for edged boards MOEs were similar to unedged ones.

Overall the 945 clear-wood specimens tested, MOE reached on average 7 577 MPa and showed a wide range of variation ($CV = 29.8\%$, range: 3 596 to 18 966 MPa). At the tree mean level, MOE ranged from 3 979 to 11 321 MPa, with a coefficient of variation close to that of boards: $CV = 16.6\%$ (Tab. III). A broad variability within individual trees was also shown: intra-tree coefficient of variability was on average 25.3%, but it varied much according to trees: $CV$ ranging from 5.5 up to 41.7%.

As a whole, mean MOEs of individual tree specimens passed from around 6 000 MPa for close-to-pith specimens up to nearly 9 000 MPa for outermost specimens showing a patent increase from pith to bark (Fig. 2).

### 3.2. Correlations among MOE estimations

As shown in Table IV, correlations between the estimated trunk MOE and MOE of the various wood pieces components were positive and significantly different from 0 ($p = 0.05$). They slightly decreased at the individual tree level from unedged boards to clear-wood specimens. The correlation reached around 0.53 between trunk MOE and mean MOE over all specimens. Specimens MOEs were best correlated with MOE of edged boards.

### 3.3. MOE at the genotype mean level

Genotype mean values ranged from 5 052 up to 8 948 MPa for trunk MOE (Fig. 3) and showed a much broader variation ($CVf = 14.9\%$) than that for diameter ($CVf = 7.2\%$). Mean MOE for unedged and edged boards were similar as shown in Figure 3 and ranged from less than 5 800 MPa up to 8 500 MPa ($CVf$ around 10.5%). Over 3 000 MPa separated clear-wood specimens MOE means of the best (F0182) and worst (F0001) performing genotypes.

At the genotype mean level, correlation coefficients with trunk MOE were much higher than at the individual tree level. It decreased from unedged boards (0.91) to specimens but it remained high whatever the positions of specimens along the radius. The best link was observed with specimens mean MOE (0.86).

Ranking of genotypes was not significantly different for trunk MOE compared to specimens MOE (Fig. 3) since the variation was observed for genotypes not significantly different from each other for specimens MOE.

### 3.4. Prediction of the modulus of elasticity of standard specimens from trunk MOE estimates

Several univariate and then multivariate linear models were tested to relate single standard specimens MOE to the different parameters available from standing trees: mean trunk MOE, mean tree height and breast height diameter. The position of specimen along the radius was added too.

The best linear regression model was obtained when combining all four parameters (Tab. V): the adjusted coefficient of determination $R^2$ reached 0.484. The model could still be a bit further improved by adding the genotype in the equation (adjusted $R^2 = 0.528$).

## 4. DISCUSSION

Direct evaluation of wood stiffness on standing trees looks particularly attractive to breeders. Indeed, they usually have to evaluate hundreds of genotypes in their genetic trials repeated over several sites, before they rank them for further selection. Requested conditions are that the proposed methodology is non-destructive, low-cost, simple and rapid to implement but also as a pre-requisite, reliable; it should allow the proper ranking of genotypes in a way consistent with standard laboratory methods for measurement of wood MOE.

**Table III.** MOE values for 'clear-wood' specimens: means, ranges and coefficients of variation at the individual and genotype mean levels.

| | Mean (range) | *CV* | Genotype means range | *CVf* |
|---|---|---|---|---|
| Outer specimens | 8 941 (3 979–13 336) | 19% | 6 562–10 597 | 13.5% |
| Inner specimens | 6 306 (4 054–9 823) | 17% | 5 323–7 370 | 9.2% |
| Close-to-pith specimens | 5 990 (3 796–8 690) | 18% | 5 200–7 391 | 12.9% |
| Specimens mean | 7 485 (3 979–10 615) | 16% | 5 802–8 882 | 12.0% |

**Table IV.** Pearson coefficients of correlation at individual tree (below diagonal) and genotype mean (above diagonal) levels.

| | Trunk | Unedged board | Edged board | Specimens mean | Outer specimens mean | Inner specimens mean |
|---|---|---|---|---|---|---|
| Trunk | | 0.905 | 0.855 | 0.861 | 0.847 | 0.795 |
| Unedged board | 0.611 | | 0.965 | 0.967 | 0.967 | 0.864 |
| Edged board | 0.563 | 0.943 | | 0.974 | 0.954 | 0.859 |
| Overall specimens mean | 0.533 | 0.818 | 0.840 | | 0.956 | 0.840 |
| Outer specimens mean | 0.484 | 0.793 | 0.815 | 0.924 | | 0.898 |
| Inner specimens mean | 0.484 | 0.626 | 0.642 | 0.836 | 0.619 | |

All coefficients are significantly different from 0 ($p < 0.005$).

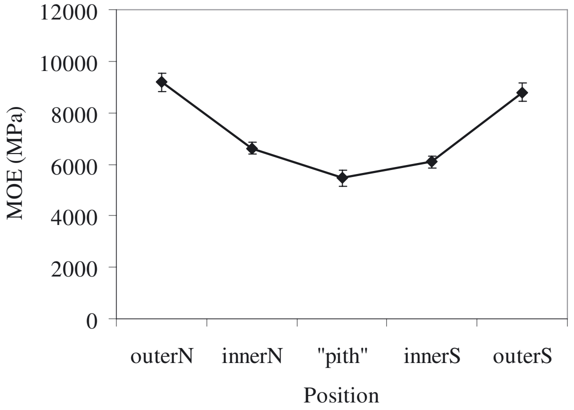

**Figure 2.** Evolution of specimens MOE from pith to bark from North to South directions (+/– 1 confidence interval, alpha = 0.05).

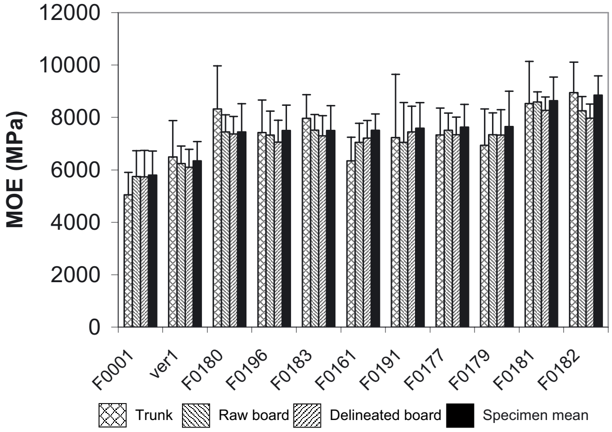

**Figure 3.** Mean genotype MOEs (and SE) in MPa for trunk, boards and clear-wood specimens.

### 4.1. Suitability of the Rigidimeter to measure MOE on standing trees

In a previous paper, Launay et al. (2000) have already shown that the Rigidimeter is a convenient device to evaluate wood stiffness on standing trees. Based on initial tests on steel and aluminium beams, the measures proved to be highly accurate. But, because the true diameter cannot be measured on standing trees (due to non-circularity) and because the diameter is raised to the fourth power, the accuracy of MOE measurements on standing trees is reduced but it should be within 95%, assuming the tree section to be circular.

Besides being non-destructive, measurements with the Rigidimeter proved also to be rather fast (7–8 min/pruned tree with 2 people), highly repeatable (repeatability coefficient over 0.99) (Launay et al., 2000) and it covers a wide range of trees with diameters from 8 up to 28 cm over bark in its latest version which was used in this study. Compared to other tools available to measure stiffness on standing trees, the Rigidimeter main weakness seems to be its size and weight (16 kg + 2 kg for the hydraulic pump), which makes the field operation slower than that of the methods based on sound velocity measurements.

Advantageously, the Rigidimeter provides bending moment measurements probably less dependent to several internal and external factors affecting the measurement of sound velocity such as the wood moisture content (Brashaw et al., 2004; Oliveira et al., 2005), the temperature (Carter et al., 2004) and internal defects. In particular, Launay et al. (2002) showed that stem taper and crookedness – a frequent defect in larch – have no significant effect on trunk MOE measured by the bending test. As well, as the wood moisture content of standing trees is over the saturation point and because it is well-known that MOE remains constant beyond this point (Carrington, 1922; Launay et al., 1986), the bending moment of standing trees is independent of the water content.

While they have been found by a number of researchers to provide reliable and accurate results (Lindström et al., 2002; Ross et al., 1999; Ross and Pellegrin, 1994; Wang et al., 2002;

**Table V.** Statistical output of multiple linear regression.

| Source | *df* | *MS* | *F* | *p*-value |
|---|---|---|---|---|
| Regression | 4 | $5.302\ 10^8$ | 188.3 | 0 |
| Residual | 868 | $2.815\ 10^6$ | | |
| | Coefficient | Std. error | *t*-value | *p*-value |
| Intercept | 989.901 | 679.055 | 1.458 | 0.1453 |
| Position | 1 430.613 | 56.812 | 25.182 | 0.0000 |
| Trunk MOE | 0.262 | 0.042 | 6.218 | 0.0000 |
| D | 13.028 | 4.104 | 3.174 | 0.0016 |
| HT | 162.180 | 59.490 | 2.726 | 0.0065 |

2004), acoustic methods also proved to better work on cut lumber than on standing trees (Lasserre et al., 2007). According to Lasserre et al. (2007), one limitation of the method is that it measures outerwood modulus of elasticity, rather than modulus across the entire tree section. The authors found a relationship between outerwood and innerwood modulus, but this relationship was not independent from several factors like stand density, genotype, bark and branch presence. Grabianowski et al. (2006) also found that stresswave velocity better measured outerwood modulus than innerwood modulus and also that it was probably affected by bark presence and characteristics.

Our results are consistent with these observations: MOE of boards determined with an acoustic method (Bing) was also more strongly linked to outer wood MOE than to inner wood MOE. In contrast, the Rigidimeter allows measurement of MOE over the entire tree section even if the latter is more influenced by the outer wood layers. In this study, MOE was linked with the same intensity to both the inner and outer wood specimens MOEs.

### 4.2. Efficiency of the Rigidimeter to rank genotypes for MOE and predict wood MOE

As already indicated by Launay et al. (2000) earlier, MOE rankings should not be affected by the type of samples used for their determinations (trunk, board and smaller specimen) as differences between samples presenting different MOE at the hygroscopic equilibrium remain rather constant once the saturation point is reached. But, the presence of knots and of other internal defects in trunk and boards should decrease MOE values relatively to MOE of standard specimens and also affect ranking.

The apparent similarity between mean MOE values of trunks, boards and specimens observed in this study (around 7 200 MPa) seems to be somehow in contradiction. Because moisture content was different between trunk and other samples and because trunks and boards included many defects while specimens did not, one might have expected trunk (and board) MOEs to be smaller than specimens MOE. In addition, MOEs obtained through static tests are usually lower than MOEs obtained on wood samples by acoustic methods. Mean MOE values hide in fact another important trend internal to trees as observed in this study along the radius: innermost specimens had indeed smaller MOEs (less than 6 000 MPa) than trunks and boards but outermost specimens over passed those with mean MOE close to 9 000 MPa. On the other side, the only moderate correlations observed at the individual tree level between trunks and (inner and outer) specimens MOE could reveal the impact of internal defects on ranking.

Prediction of single wood specimens MOE from trunk MOE and other tree dendrometrical characteristics proved reasonably good insofar the position (along the radius) of the sample is given. The model became even better once the genotype is taken into account. This result stresses again the importance of the position of the samples within the tree as the successive wood layers of the trunk have different mechanical properties. This explains also why trunk MOE is not simply related to the arithmetic average of MOE.

At the genotype mean level, high correlation coefficients ($r$ = 0.80–0.86) were found in this study between standing tree MOE and MOE of standard conditioned wood samples and the ranking of genotypes proved to be efficient. Similar findings were found by Launay et al. (2000) in a preliminary validation study on Douglas-fir trees of about the same age (29 trees in total from 8 clones). Tight correlations were found at the genotype mean level ($r$ = +0.74–0.79, significant at 5%) between trunk MOE obtained with the Rigidimeter and 1.7 m long-boards MOE (vibration test). As well, Koizumi and Ueda (1986) showed for various conifers including larch, fir and spruce the validity of their bending device to evaluate MOE on standing trees. Correlation coefficients with standard MOE evaluated from clear-wood specimen reached in their study over 0.90 among trees from the different species.

Finally, the trunks and the boards were characterised at the genotype mean level by MOE values rather similar to those of clear-wood specimens (mean difference with unedged boards: 418 MPa; with clear-wood specimen: 458 MPa). Consequently, all these findings confirm that the Rigidimeter is reliable in estimating genotypes mean value for wood stiffness but more importantly, it proves to be efficient in ranking genotypes.

From a practical point of view, possibilities offered by direct estimation of wood stiffness on standing trees become particularly attractive for tree breeders as far as the method allows routine evaluation, permits to display a high enough genetic variability among genotypes and finally allows the efficient ranking of genotypes for further selection.

These results together with those already reported by Launay et al. (2000; 2002) confirm the scientific interest of the Rigidimeter to directly evaluate wood stiffness on standing trees and its interest for ranking and selecting genotypes in the framework of tree breeding programmes of conifers.

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