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Keywords

Beech; Wood properties; Variability; Radial variation; Juvenile transition

Abstract

The radial variation of wood properties, especially within the juvenile transition, exhibit patterns typical of the species, with, however, a strong dependence on growth conditions. Data obtained on beech (*Fagus sylvatica* L.) from several high forest stands in European countries have been revisited with a focus on this aspect. Laboratory measurements of ring width (*RW*), wood specific gravity (*SG*) and wood specific modulus (*SM*), were used to examine aspects of juvenility corresponding to young stages of the tree. The radial variations of *RW*, *SG* and *SM*, averaged over 86 trees, were close to the "typical radial pattern" of juvenile wood for softwood plantation trees: decrease in *RW* and increase in *SG* and *SM* from pith to bark in the juvenile phase. But *SG* only increased in the very first rings, then remained more or less constant. Furthermore, for all three parameters there were many discrepancies in the pattern of variation between trees and between plots. This is a good indication that the mechanical juvenility of the wood was more related to the mechanical conditions experienced by the trees in the young ages than to the age of the tree as such, as is the case for other features such as fibre length. Moreover, no significant influence of red heart occurrence on wood properties was observed.

Notations and abbreviations

ANOVA	analysis of variance
CV	coefficient of variation
D	density
DP	distance to pith
L, *L*	longitudinal direction, , specimen length in L direction
MFA	microfibril angle
MOE	modulus of elasticity
R, *R*	radial direction, specimen length in R direction
RW	ring width
SG	specific gravity (ratio of *D* over water density)
SM	specific modulus (ratio of *MOE* over *D*)
T, *T*	tangential direction, specimen length in T direction
TRP	typical radial pattern
W	specimen weight

1. Introduction

Wood growth is the process used for tree building (Thibaut 2019) including simultaneously primary growth by elongation or creation of twigs and secondary growth by thickening of existing woody axes. The variation of growth parameters characterizing wood structure and properties depends on tree ontogeny and adaptation to changes in the environment of the tree during its life. Juvenility, in particular, describes the evolution of wood parameters during the early years of the stem. But the environment of the tree (access to light, wind influence, effect of gravity) also changes during the young period of tree growth and mechanical adaptation of wood growth occurs in response to these changes.

Secondary growth is performed by living wood cells in the cambial zone: stem cells of cambium itself and daughter cells (Raven et al 2007, Savidge 2003, Déjardin et al 2010, Thibaut 2019) It consists of the following successive steps: division of the cambium stem cells into daughter cells; expansion of daughter cells until the end of primary wall formation; thickening of the fibre (or tracheid) cell walls until the end of secondary wall formation; lignification of the whole cell wall, including the compound middle lamella; programmed fibre and vessel cell death. During this cambial activity mechanical wood features are achieved. They can be described by ring width, result of combined cell division and expansion, density expressing cell wall thickening, specific modulus determined by the cellulose micro-fibril organisation in the cell wall, and maturation strain resulting from the final polymerization of lignin and other macromolecular processes (Thibaut & Gril 2021). All secondary growth descriptors display spatial variation within a portion of trunk, in the 3 cylindrical directions: transversely across radii (Tar), around the perimeter (Ap) and longitudinally along the stem (Las), called variation "TarApLas" within the tree by Savidge (2003). These variations are linked either to the effect of cambial age (called juvenility) or to the adaptation of the wood growth to external conditions (climate, light availability, accidental leaning, etc.).

Variations around the perimeter in a given ring are related to a mechanical adaptation in the control of posture, i.e. oblique growth in a given direction (in the case of coppice or for the search of light) or progressive change of axis curvature, either to restore verticality after accidental inclination of the tree (Alméras et al 2005, Alméras and Clair 2016) or to change the orientation of the branches after the death of the apex (Loup et al 1991). The variations along the stem deals with primary growth: i) succession of connected zones and free-from-branching portions of the axis and ii) ageing of the terminal bud in the successive growth unit. Apart from the vicinity of the branching zones, the variations are rather slow (Savidge 2003). Radial variations, from pith to bark at a given height level can be divided in two types: i) intra-ring short distance changes mostly due to intra-annual climatic changes and ii) variations of mean intra-ring properties linked both to cambium ageing (juvenility) and to the adaptation of secondary wood growth to tree mechanics at each growth step (gravity and wind forces depending on tree slenderness and crown development). It is not easy to separate the effects of age per se (time since birth of cambium in the growth unit) and of the mechanical situation of the tree at different growth ages (light availability, wind protection).

The biggest variations in dimensions and environment for a given tree over time occur during the young ages, and so are the variations of wood properties showing higher radial gradients in the inner part of the axis, called juvenile wood or core wood depending on the authors (Lachenbruch et al 2011) and their opinion concerning the main influencing factor (juvenility or adaptation).

A good description is given in Bendtsen & Senft (1986) for a softwood and a hardwood. Loblolly pine (Fig. 1) is an example of the typical radial pattern (TRP) of juvenility (Lachenbruch et al 2011): i) initial increase of tracheid length, specific gravity (*SG*) and specific modulus (*SM*), initial decrease of ring width (*RW*) and microfibril angle (*MFA*); *MFA* variations are closely, negatively related to those of *SM*. This is the general case in softwood plantation trees (Cown & Dowling 2015, Larson et al 2001).

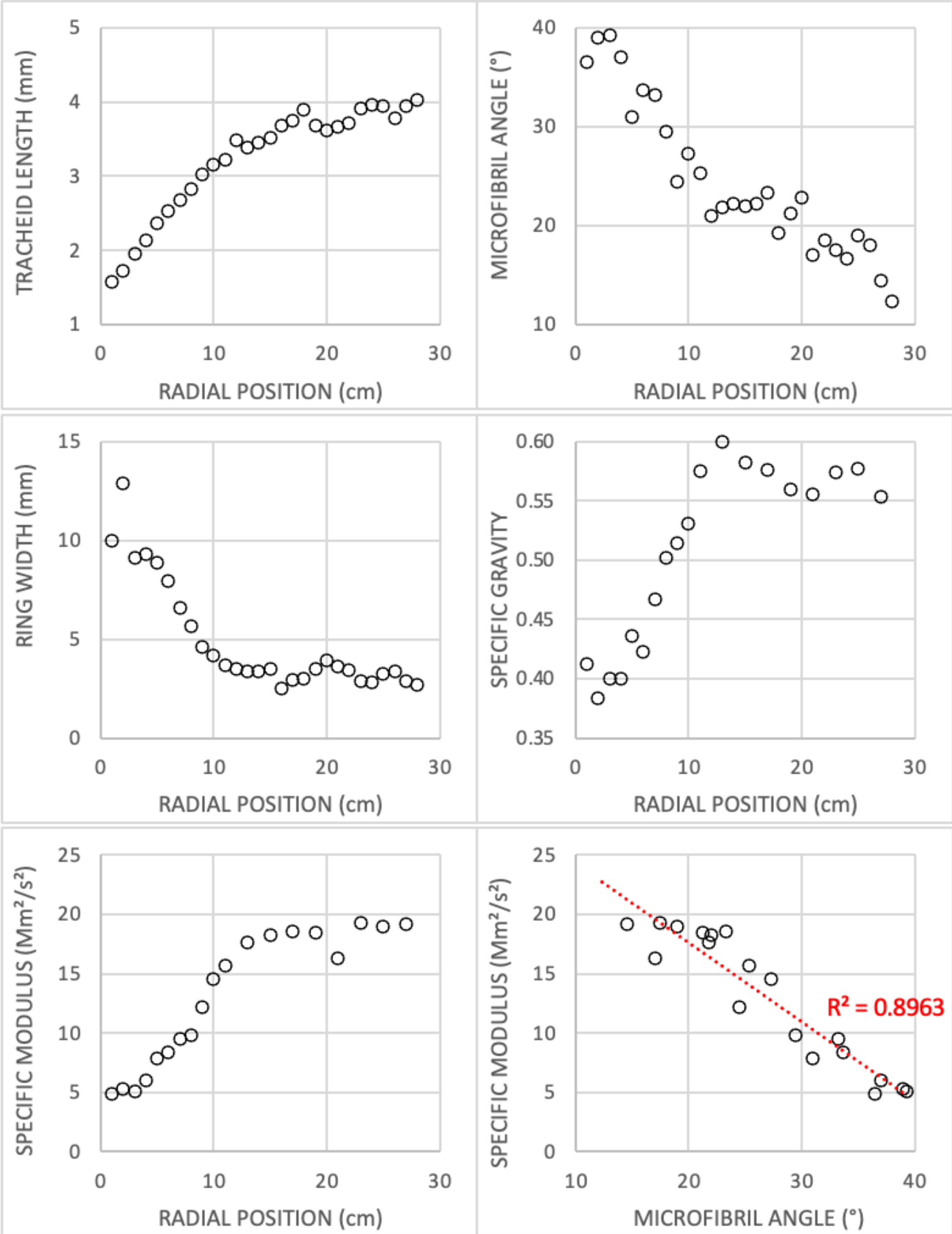

Fig. 1: Radial variations for Loblolly pine, after Bendtsen & Senft (1986).

The same pattern applies to Eastern cottonwood (Fig. 2).

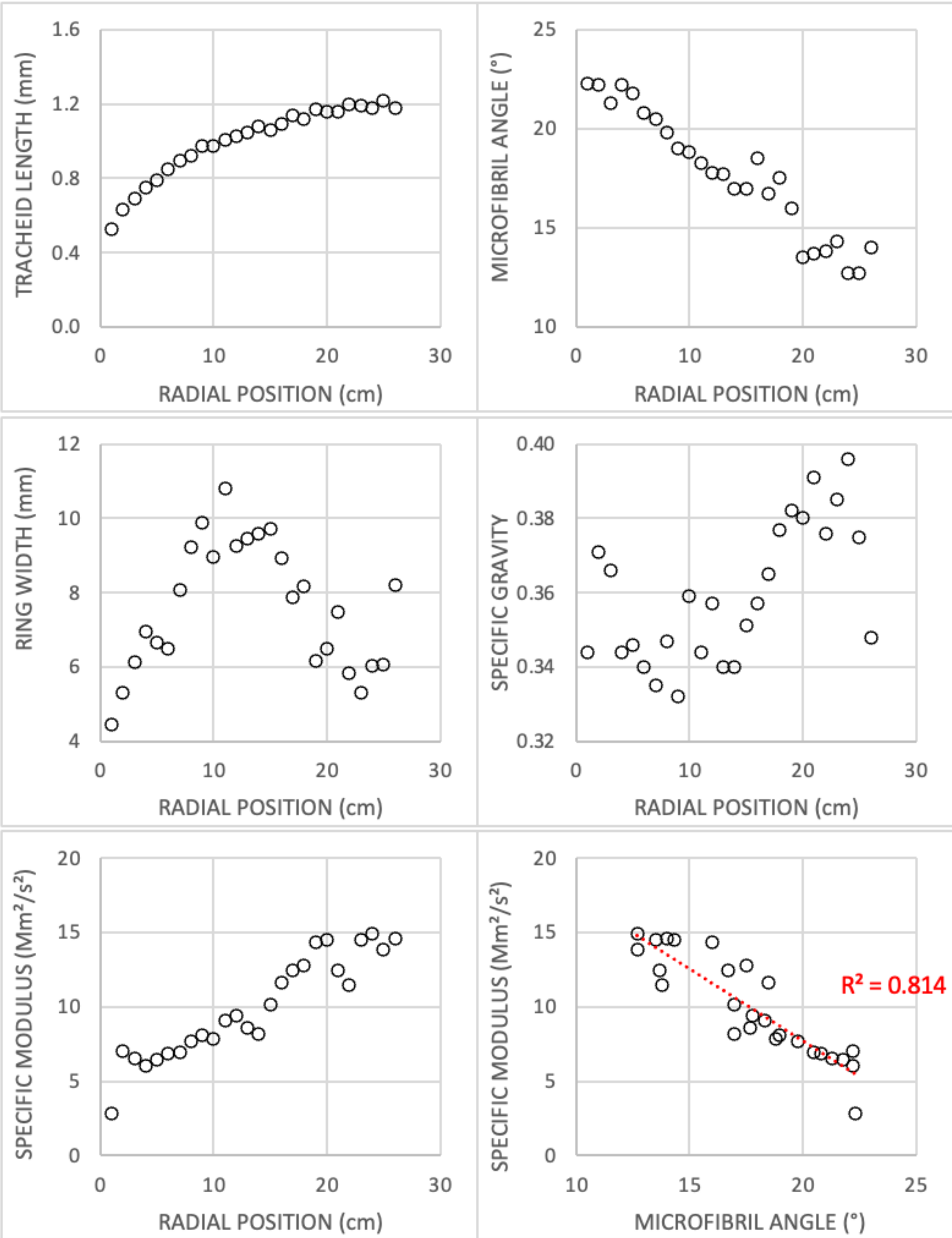

Fig. 2: Radial variations for Eastern cottonwood, after Bendtsen & Senft (1986).

Variations in tracheid or fibre length always share the same initial positive gradient for all trees, whether softwood or hardwood (Koubaa et al 1998, Larson et al 2001, Bhat et al 2001, Bao et al 2001, Kojima et al 2009). This parameter is important for the paper industry (Koubaa et al 1998) but is not cited as a factor influencing the mechanical properties of wood (Kollmann & Côté 1968, Kretschman 2010). The results of initial variations of *RW*, *SG* and *SM* can vary considerably from tree to tree, with flat, positive or negative initial gradients (Bhat et al 2001).

In this paper, the data obtained on a large panel of beech trees will be exploited to characterize the patterns of radial variation of wood properties in beech. Beech wood has always the same basic anatomy and chemical composition which are signatures of the species *Fagus sylvatica* L. But within this physical and chemical pattern, quantitative variation occurs, linked to growth adaptation to historical context (tree age, climate, forest management…) of the living tree at the moment of the new layer forming.

Although heartwood and sapwood in healthy beech trees can scarcely be told apart, a referred to as “red heartwood” is often observed (Liu et al 2005), with an inner distribution possibly dependent on the presence of branch scars and knots (Wernsdörfer et al 2005) triggering the massive arrival of oxygen (Sorz & Hietz 2008). Although technological properties do not seem to be influenced by the discoloration (Pöhler et al 2006), it affects the commercial value of the products (Trenčiansky et al 2017). Consequently, this factor will be also considered in the analysis.

2. Material and methods

2.1. Material

In nine plots representative of forest management in Western Europe (Becker & Beimgraben 2001, Jullien et al 2013), 10 trees (among 86 in total) were selected for the measurement of wood properties. The types of management and plot ages are recalled in Table 1.

Table 1. Characteristics of the studied plots

Forest management	age (years)	Plot number								
		1	2	3	4	5	6	7	8	9
Classical even-aged forest, rather flat zone	100-130	o		o	o	o	o			
Classical even-aged forest, steep terrain (mountain)	120-150		o						o	
Uneven-aged high forest, rather flat zone	60-120							o		
Former middle forest later transformed in even-aged high forest	60									o
Country code		AT	AT	DK	FR	DE	DE	CH	CH	DE

One small log of 50 cm length was cut at a height of 4 m for each tree. Each small log was cut into radial boards, through the pith, from North to South. These boards were air-dried to an average moisture content of 13.5 % (equilibrium at 20°C and 65% RH) and cut into 1259 rods of 20 mm in radial, 20 mm tangential and 360 mm longitudinal direction, from the pith outwards (Fig. 3). Those with irregularities or cracks were discarded.

The rods were numbered according to their position in the board, their distance to pith (*DP*) was measured, and their orientation (North or South) was noted. At the same time, the number of rings at both ends of the samples was recorded and the mean annual ring width of the rod (*RW*) was calculated as the ratio of the mean radial dimension to the number of rings. Each sample located at a distance lower than 10 cm from the pith was considered as a “core” sample. The presence of red heartwood was also noted for the rods located in the core, in relation to a previously published work (Liu et al 2005).

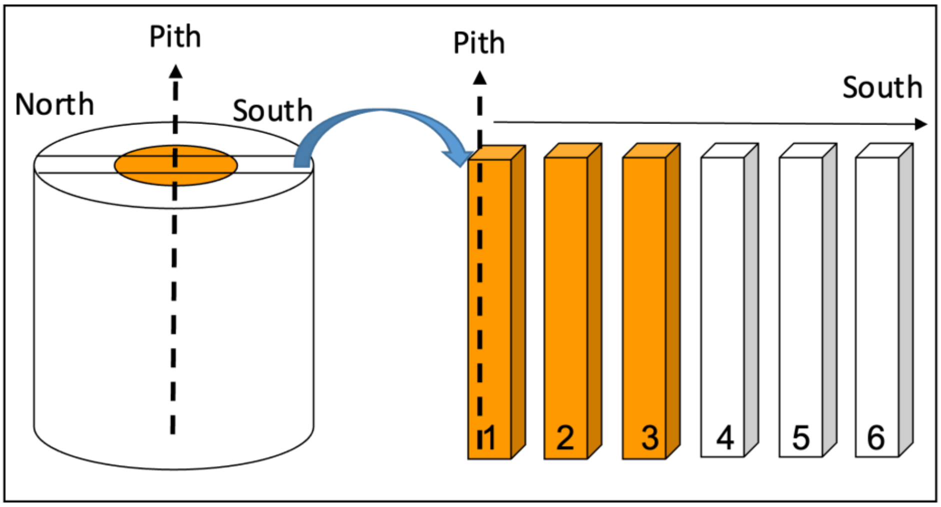

Fig. 3: Diagram of the sawing of the rod after the sawing of a North-South diametrical board. Numbering both for Northern and Southern parts of the board start with pith position. The coloured parts evoke the case of redheart occurrence.

In each case, the occurrence of rods for each successive radial position within the trees or plots was examined (Fig. 4). Up to 18 cm from the pith, all the plots were concerned and there were always more than 70% of the trees concerned, values lower than 100% being due to defect occurrence close to the pith. This proportion decreased rapidly for larger distances from the pith, due to variable log size. It is therefore preferable not to use rods with a radial distance of more than 18 cm to calculate the mean values of the parameters at the global scale.

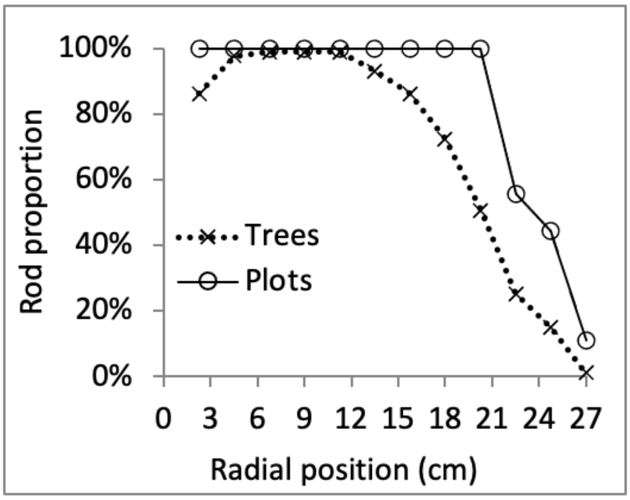

Fig. 4 Percentage occurrence of rods for each successive radial position within trees or plots 100% means that there are used rods at a given radial position in every tree or every plot.

2.2. Measurement of properties.

All measurements were done in a regulated room at a temperature of 20°C and a relative humidity of 65%.

The density (*D*) was calculated by measuring the weight (*W*) and the dimensions *R*, *T*, *L* of the rod in direction R, T, L, respectively: $D = W/(R.T.L)$. The specific gravity (*SG*) is the ratio between *D* and water density.

To measure the specific modulus (*SM*, $10^6 m^2/s^2$), each rod is positioned on fine wires and set in free vibration by a hammer stroke. The analysis of the sound vibration by fast Fourier transform gives the values of the three highest resonance frequencies which are interpreted using

Timoshenko solution (Brancheriau & Baillères 2002). The Young modulus of wood (*MOE*) can be calculated as: $MOE = SG.SM$.

2.3. Statistical analysis

Basic statistical analyses were performed using XLSTAT software. The data description table includes the number of data, the minimum, maximum and mean values for each parameter, as well as the coefficient of variation (*CV*). The normality of the distribution is verified by Shapiro-Wilk test. A Pearson correlation analysis is used in the case of a normal distribution, and a Spearman correlation analysis in the case of a non-normal distribution, which is the majority of cases. Analysis of variance and variance components was carried out using the R software (R Core Team 2018), using a nested ANOVA design where a random "tree" factor is nested within the "plot" factor, and the "core" factor nested within the "tree" factor. Sample orientation (North or South) was accounted for through an independent "orientation" factor.

3. Results

3.1 Analysis of variance and variance components

ANOVA was highly statistically significant on each of the three measured variables (*RW*, *SG* and *SM*). Plot, tree within plot and core within tree were all very highly significant factors ($P < 10^{-16}$) for the three studied variables, while orientation is a significant factor only for specific modulus ($P = 0.00012$). The share of variance of each factor for each variable is displayed in Table 2. For *RW*, the core factor represents the largest part of variance, followed by the plot and tree factors. For *SG* and *SM*, the tree factor is the largest part of variance. The orientation factor always represents a negligible part of variance, even when it is statistically significant (*SM*).

Table 2. Results of the variance component analysis: share of variance for each factor (%) and significance of the factors (*** $P<10^{-3}$, ° $P>0.05$)

Factor	RW	SG	SM
Plot	21.9***	14.0***	15.4***
Plot/tree	9.2***	36.4***	28.6***
Plot/tree/core	29.5***	18.2***	14.6***
Orientation	0.0°	0.0°	0.8***

3.2. Radial variations of properties

By giving positive values for the distance to the pith on the North side and negative values on the South side, it is possible to draw the South-North profile of each parameter (*RW*, *SG*, *SM*, *MOE*) for each tree, as a function of the diametrical position (*DP*). If there was an increase of the parameter from pith position, the profile is noted "Up", "Down" for the reverse case and "Flat" when the variation was not clearly up or down. In case of clear asymmetry between the Southern and Northern parts by visual observation, the sample was considered as asymmetric (Fig. 5), otherwise it was noted as symmetric.

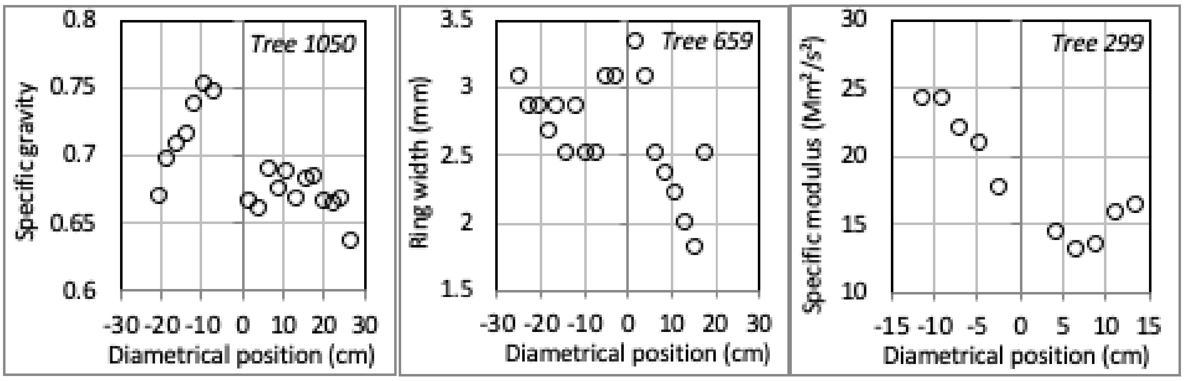

Fig. 5 Examples of clearly asymmetric North-South profiles.

There was a large majority of symmetrical patterns (Table 3).

Table 3 Proportion of profile types per plot within each wood parameter.

Para.	Ring width				Density				Specific modulus			
PLOT	Up	Down	Flat	Sym	Up	Down	Flat	Sym	PLOT	Up	Down	Flat
1	57%	43%	0%	70%	0%	25%	75%	40%	1	57%	43%	0%
2	67%	11%	22%	90%	11%	0%	89%	90%	2	67%	11%	22%
3	63%	0%	38%	80%	30%	0%	70%	100%	3	63%	0%	38%
4	70%	10%	20%	100%	20%	0%	80%	50%	4	70%	10%	20%
5	43%	14%	43%	70%	100%	0%	0%	60%	5	43%	14%	43%
6	86%	0%	14%	88%	50%	0%	50%	100%	6	86%	0%	14%
7	22%	56%	22%	90%	43%	14%	43%	70%	7	22%	56%	22%
8	67%	17%	17%	60%	100%	0%	0%	70%	8	67%	17%	17%
9	14%	57%	29%	88%	40%	0%	60%	63%	9	14%	57%	29%
Mean	54%	23%	23%	82%	44%	4%	52%	71%	Mean	54%	23%	23%

Para.: Wood parameter; Up: initial increase of the parameter from pith to bark; Down: initial decrease of the parameter from pith to bark; Flat: no clear initial increase or decrease; Sym: proportion of globally symmetrical profiles between North and South directions.

In accordance with the results of the variance component analysis, there were no noteworthy difference between the Northern and Southern samples (Table 4).

Table 4 Comparison of parameter values North and South.

Position (Nb)	*RW* (mm)	*SG*	*SM* ($10^6 m^2/s^2$)	*MOE* (GPa)
North (637)	2.32	0.695	22.06	15.33
South (622)	2.28	0.694	22.39	15.54
% Sym.	82%	71%	76%	70%

RW: mean ring width; *SG*: mean specific gravity; *SM*: mean specific modulus; *MOE*: mean longitudinal modulus of elasticity; Nb: number of rods; *%*Sym: proportion of diametrical patterns considered symmetrical for each parameter.

There were notable differences between trees for each parameter, both in value and in pattern. In Fig 6, the range of variation of the parameters values is given as a function of the position along the diameter, as well as the corresponding number of rods used for the calculation. There was no systematic difference between the Northern and Southern samples (Table 1, Fig. 6). It was thus possible to mix the beech rods of the Northern and Southern specimens for further analysis of the mean radial variation patterns at the global or plot level.

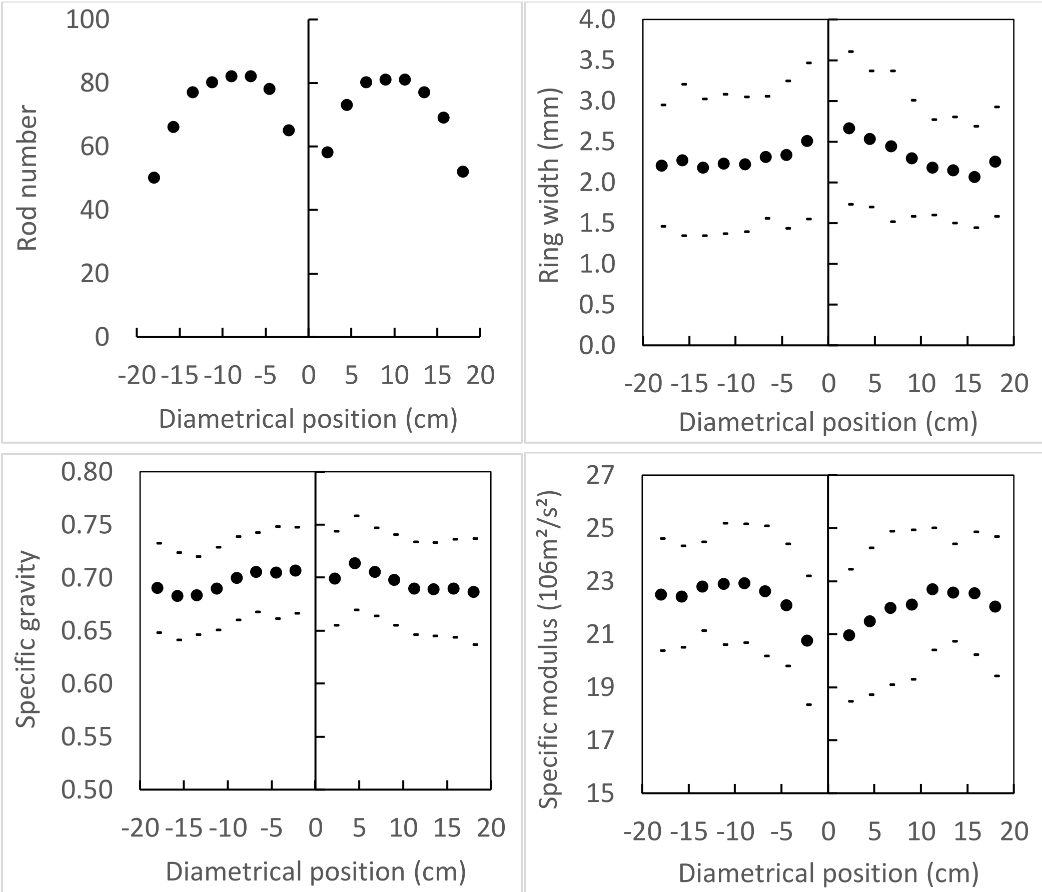

Fig. 6 Number of rods and parameter values for all trees as a function of diametrical position (DP)
Bolt dots: mean value; thin dashes: mean value + or – standard deviation.

Moreover, some trees have a part of red core-wood portion and the effect it may have on properties was investigated. All trees (25) without any red rod (except sometimes one near the pith) were considered as white beech while all trees with more than two red rods were considered as red beech. Fig. 7 shows the number of rods used for each radial position and the mean radial variations of properties for red and white beech trees. Due to the variability between the trees, no noteworthy difference could be observed between the mechanical properties of red and white beech wood.

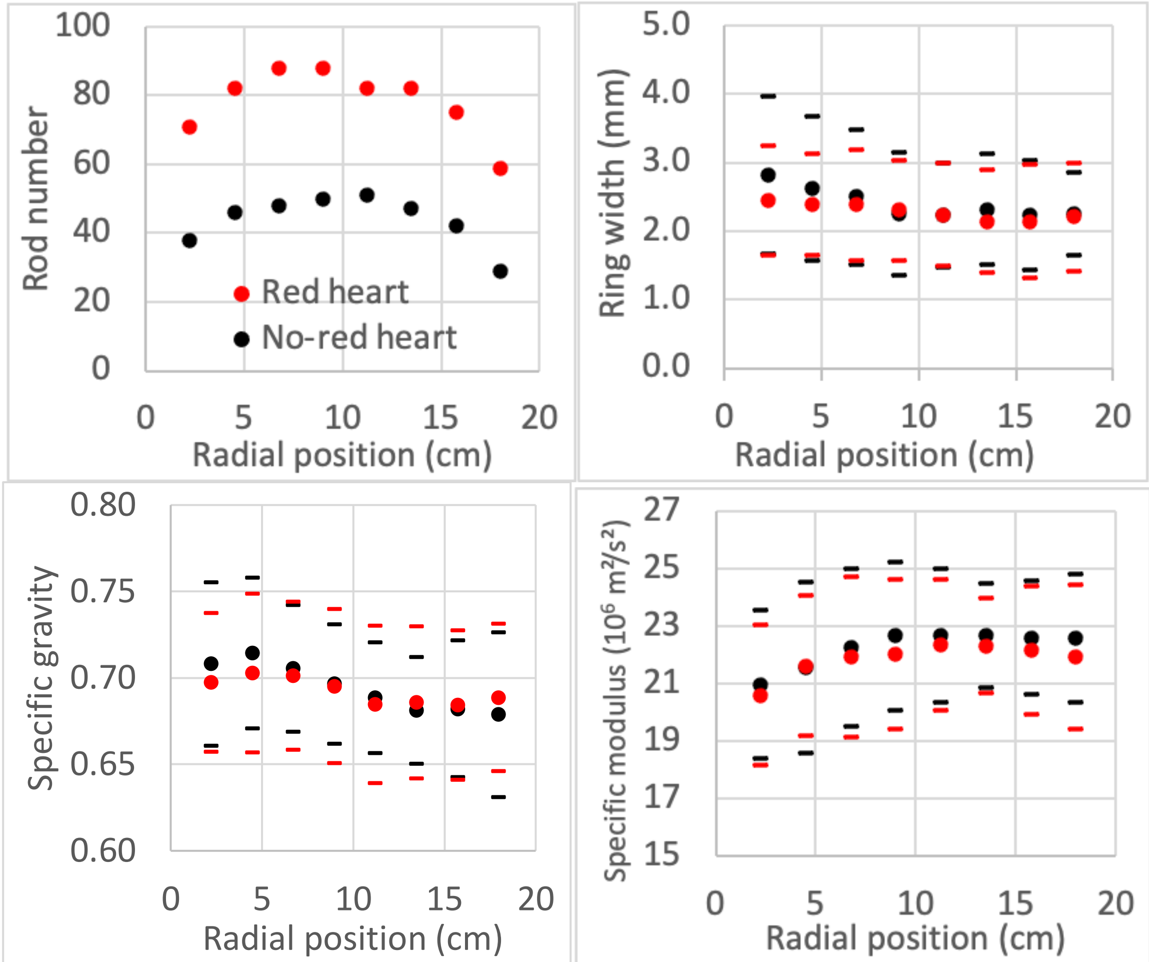

Fig. 7 Number of rods and parameter values for all red and no-red hearted trees as a function of radial position. Bolt dots: mean value; thin dashes: mean value + or – standard deviation. Red dots: red heartwood; black dots white heartwood

It is thus possible to mix Northern and Southern specimens of red and white beech rods for further analysis of the mean radial variation patterns at the global or plot level.

The global mean radial patterns for these beech trees were as follows (Fig. 8):

- *RW* decreases regularly (2.6 to 2.2 mm) from pith to bark;
- *SG* increases a little (0.703 to 0.709) at the beginning (up to about 4 cm radius) and decreases thereafter (0.709 to 0.686), but the variations are small;
- *SM* increases (20.8 to 22.8 m^2/s) for a rather long time (up to about 12 cm radius) and then decreases (22.8 to 22.2 m^2/s^2) regularly;
- the *MOE* pattern is very similar to the *SM* pattern.

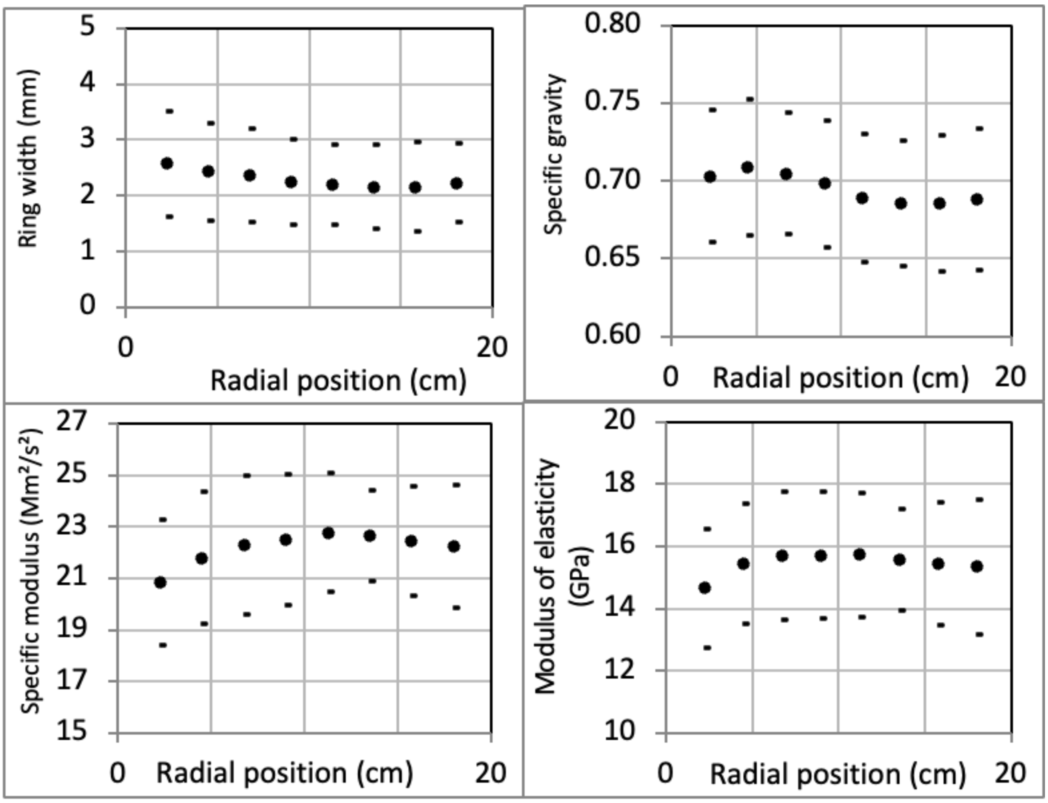

Fig. 8 Mean radial distribution of indicators and modulus of elasticity for all rods.
Bolt dots: mean value; thin dashes: mean value + or – standard deviation. bè§§§y!

The variability between trees (coefficient of variation) is high for *RW* but low for *SG*. As will be seen later in Table 7, it is slightly higher for *SM* and *MOE*.

The mean patterns of the plots (Fig. 9) are more irregular due to the smaller number of rods, but the global mean pattern is the most frequent. There are differences between plots, in the mean level of properties and sometimes in the pattern, mainly for *RW*, with some plots having an increasing *RW* (plots 7 and 9). Others exhibit a decrease followed by an increase of *RW*, with low mean values (plots 2 and 8).

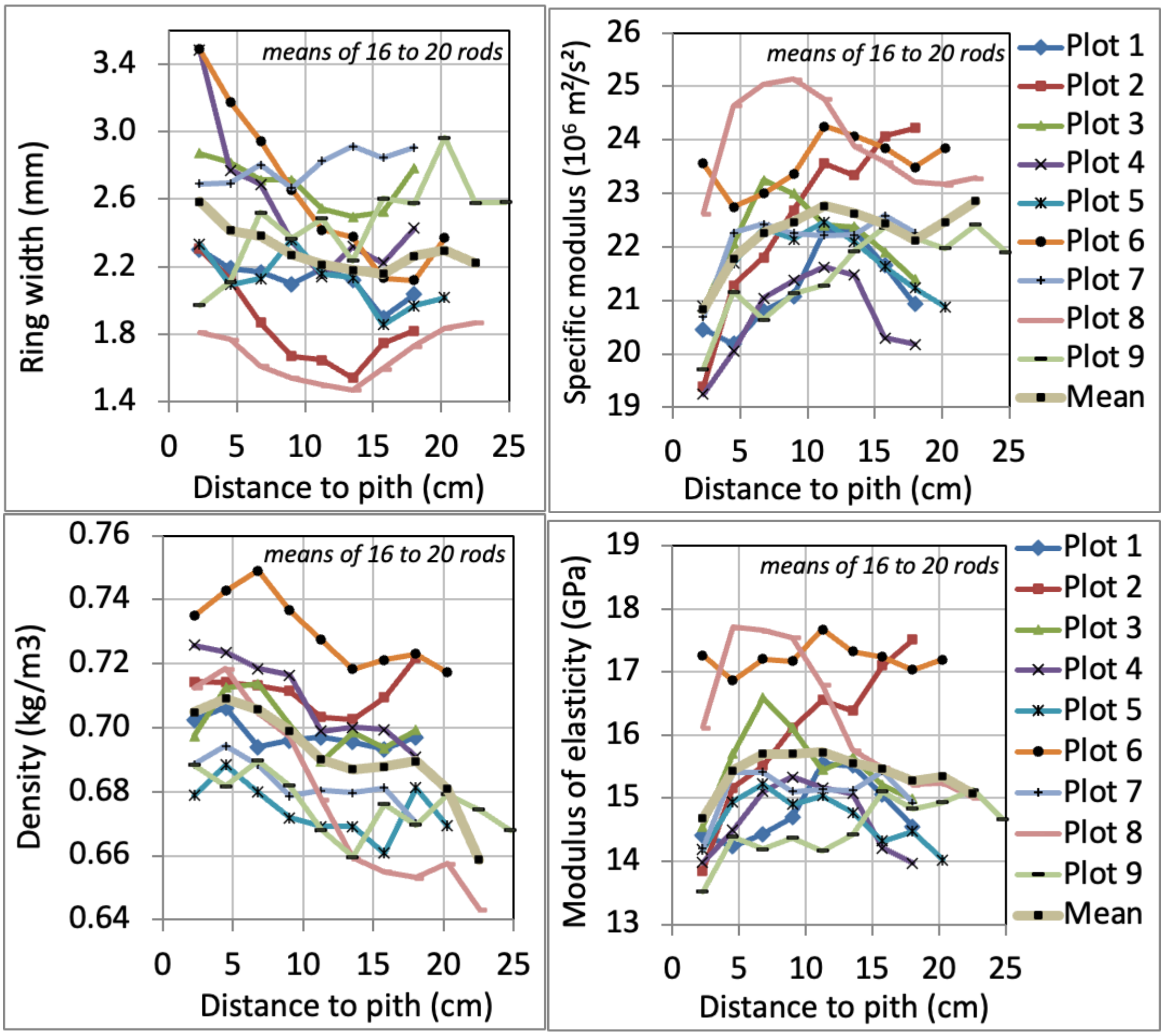

Fig. 9 Mean radial variations of properties at the plot level

Mean: mean values for all rods at each radial position. For plot characteristics, see Table 1

3.3. Global results

<u>3.4.1. Global results at rod level</u>

Table 5 and 6 give the global description and correlation within the data for all samples (1259 rods), respectively. The variation of *SG* between samples is very low (coefficient of variation 6%).

Table 5 Parameter description for all rods

1259 rods	*RW*	*SG*	*SM*	*MOE*
Minimum	0.67	0.55	11.08	8.00
Maximum	6.67	0.83	27.49	21.30
Mean	2.30	0.69	22.22	15.44
Max/min	10.00	1.51	2.48	2.66
Coefficient of variation	35.0%	6.2%	10.9%	13.0%

RW (mm): ring width; *SG*: specific gravity; *SM* (10^6m²/s²): specific modulus;
MOE (GPa): longitudinal modulus of elasticity.

Table 6 Correlation table for all rods

1269 rods	*RW*	*SG*	*SM*	*MOE*
RW	**1**	**0.215**	**-0.313**	**-0.167**
SG		**1**	0.047	**0.506**
SM			**1**	**0.884**
MOE				**1**

RW: ring width; *SG*: specific gravity; *SM*: specific modulus; *MOE*: longitudinal modulus of elasticity.
Bold numbers: correlation significant at 0.01% level.

There is no significant correlation (at the 5% level) between *SG* and *SM*. *RW* has a very significant correlation (at the 0.1% level) positively with *SG* and negatively with *SM*. Thus, the correlation between *RW* and *MOE* is negative with a lower coefficient of determination (3%). In the determination of *MOE* from *SM* and *SG*, the coefficient of determination (square of the correlation coefficient given in Table 5) is three times higher for *SM* (78%) than for *SG* (26%).

3.4.2. Global results at tree level

Tables 7 and 8 give the description and correlation table for tree dimension and mean per tree. Variability of parameters is significantly lower for tree mean values, and notably low for *SG*. Except for *RW*, the mean wood properties per tree show rather low variations between trees (very low for *SG*). Among the wood properties, *RW* and *SM*, *SM* and *MOE*, *SG* and *MOE* remain highly significantly correlated (0.1% level) at the tree level.

Table 7 Parameter description for tree mean values

86 trees	*RW*	*SG*	*SM*	*MOE*
Minimum	1.29	0.63	17.6	12.0
Maximum	4.78	0.78	25.6	19.3
Mean	2.28	0.70	22.4	15.6
Max/min	3.70	1.24	1.46	1.60
Coefficient of variation	24.9%	4.8%	7.6%	9.5%

RW (mm): ring width; *SG*: specific gravity; *SM* ($10^6 m^2/s^2$): specific modulus;
MOE (GPa): longitudinal modulus of elasticity.

Table 8. Correlation table for all trees

86 trees	*RW*	*SG*	*SM*	*MOE*
RW	**1**	0.122	**-0.388**	-0.252
SG		**1**	0.140	**0.602**
SM			**1**	**0.874**
MOE				**1**

RW: ring width; *SG*: specific gravity; *SM*: specific modulus; *MOE*: longitudinal modulus of elasticity.
Bold numbers: correlation significant at 0.01% level.

3.4.3. Global results at plot level

Table 9 gives the description of tree dimensions and mean wood properties per tree for the 9 plots and Table 10 the correlation table for all plots. Except for *RW*, the mean wood properties per plot all show very little variation between plots.

Table 9 Parameter description for the 9 plots mean values

Plot	Nb trees	*RW*	*SG*	*SM*	*MOE*
1	10	2.06	0.70	21.5	15.0
2	10	1.80	0.71	23.1	16.4
3	10	2.63	0.70	22.2	15.6
4	10	2.50	0.71	21.2	15.1
5	10	2.12	0.68	21.9	14.8
6	8	2.57	0.73	23.7	17.3
7	10	2.84	0.68	22.0	15.1
8	10	1.63	0.68	24.1	16.4
9	8	2.50	0.67	21.7	14.6
Max		2.84	0.73	24.1	17.3
Min		1.63	0.67	21.2	14.6
Mean		2.29	0.70	22.4	15.6
Max/min		1.74	1.08	1.14	1.18
Coefficient of variation		16.9%	2.6%	4.2%	5.5%

RW (mm): ring width; *SG*: specific gravity; *SM* ($10^6 m^2/s^2$): specific modulus;
MOE (GPa): longitudinal modulus of elasticity.

At the plot mean level, only the causal relationship between *MOE* and *SG* or between *MOE* and *SM* remains significant at the 0.1% level (Table 10).

Table 10. Correlation table for all plots

9 plots	*RW*	*SG*	*SM*	*MOE*
RW	**1**	0.154	-0.446	-0.266
SG		**1**	0.252	0.671
SM			**1**	**0.886**
MOE				**1**

RW: ring width; *SG*: specific gravity; *SM*: specific modulus; *MOE*: longitudinal modulus of elasticity.
Bold numbers: correlation significant at 0.1% level.

5. Discussion

Most of the papers on juvenile wood refer to plantation, either of softwoods or hardwoods (Bensend and Senft 1986, Kojima et al 2009, Bhat et al 2001, Bao et al 2001). Fibre length which is not referred as a mechanical factor (Kretschmann 2010) always increases from pith to bark (Kojima et al 2009, Koubaa et al 1998) until a distance considered as the limit of juvenile wood. For softwoods, the "typical radial pattern" for mechanical factors (Lachenbruch et al 2011) is always the case for fast-growing plantations. It is characterized by a decrease of *RW* and an increase of both *SG* and *SM* from pith to bark until a juvenile core limit. For hardwoods this is not always the case, and *SG* can be more or less flat (Bendtsen & Senft 1986, while *SM* can be high near the pith and decrease for trees growing in dense tropical forest (Mc Lean et al 2011).

There are few published results relating to radial variations of mechanical parameters in large trees of high forests that are not the result of plantation. Plourde et al (2015) studied radial density variation for 91 tropical species (Costa Rica). 42 over 74 had a net variation in density, 37 with increasing TRP type and 5 with decreasing "anti TRP" type. Secondary forest species (open environment in juvenile phase) had the clearest positive variations (low juvenile density), primary forest species (closed environment in juvenile phase) were the only anti-TRP species with a lower variation (high internal density). This is similar to what was found in French Guiana (Mc Lean et al 2011). On *Bagassa guianensis*, a fast-growing secondary forest tree of French Guiana, Bossu et al (2018) observed a general TRP pattern for AMF and density, very clear for density (0.3 to 0.9 along the radius). In addition, they identified a TRP pattern for interlocked grain: low in the inner zone and then increasing sharply towards the bark, resulting in a net increase in splitting fracture energy. Longuetaud et al (2017) studied 3 broadleaved trees: oak, beech, sycamore maple and two softwoods: fir and Douglas fir. The TRP model was valid for maple and Douglas fir, but for oak the density decreased instead of increasing. For fir and beech, the profile was bell-shaped (beech) or U-shaped (fir) with slight variations. Purba et al (2021) studied density and AMF in oak and beech for dominated, small-diameter trees harvested in thinning. Overall, the TRP applies to both cases

Authors measuring mechanical properties generally do not take into account the specific modulus, which is highly correlated with AMF, but being less noisy yields stronger statistical relationships (R^2).

In Europe, old growth beech forests can have different forest origins: i) even-aged (France or Germany) or uneven-aged high forest (Switzerland), coppicing with standards (France) or conversion of coppice forest into high forest (Ciancio et al 2006) (Germany, France) but are very rarely the result of plantations (none in the 9 plots). *Fagus* is known for its shade tolerance and ability to grow very slowly under a closed canopy (Collet et al 2011) and most forest plots undergo more or less severe thinning before final harvesting, which leads to an increase of *RW* due to better access to light (Noyer et al 2017). This is reflected in the different mean *RW* radial patterns for the 9 plots (Fig. 9). For plots 7 (uneven-aged high forest) and 9 (middle forest transformed in even-aged high forest), a clear increase of *RW* is observed in the young ages, while the reverse and classical pattern is true for plots 1, 4, 5 and 6 (all even-aged forest in flat area). Similar results were found on younger beech trees (Bouriaud et al 2004). The low *RW* values for plots 2 and 8 (even aged, steep terrain) can be expected in a mountainous area, and the observed increase of *RW* after an initial decrease possibly due to thinning operations.

The lack of visible difference in mechanical properties between red and white beech wood confirms the observations by Pöhler et al (2006).

6. Conclusion

As a mean for these high forest beech trees, the radial patterns of variations are partly similar to the typical radial pattern for *RW* and *SM*. *SG* has a very small decreasing variation. But looking tree by tree, there are all types of patterns (increasing or decreasing at the beginning) for all parameters (*RW*, *SG* and *SM*). This supports the hypothesis of an “acclimation” for “mechanical” juvenility.

There is a very significant influence of forest plot on the 3 mechanical parameters sharing around 15% of the variance for each of them. The biggest sharing of variance comes from tree within the plot with a significant influence of the radial position (20 cm diameter core).

Due to the very low variability of the *SG* of beech wood, the variations of *SM* are much more important than those of *SG* in order to explain the variations of *MOE*.

Acknowledgments

The data were obtained thanks to the support of European Commission through the FAIR-project CT 98-3606, coordinated by Prof. Gero Becker. The financial support of CNRS K. C. Wong post-doctoral program and China Scholarship Council must be also acknowledged.

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