Influence of Former Farmland on the Characteristics and Properties of Scots Pine (*Pinus sylvestris* L.) Tree Tissue

Tomasz Jelonek,[a,]* Magdalena Arasimowicz-Jelonek,[b] Jarosław Gzyl,[b] Arkadiusz Tomczak,[a] Piotr Łakomy,[c] Witold Grzywiński,[a] Agnieszka Remlein,[a] Katarzyna Klimek,[a] Joanna Kopaczyk,[a] Roman Jaszczak,[d] and Robert Kuźmiński [e]

This paper compares the characteristics and properties of wood from trees grown on forest land with trees grown on former farmland. The first generation of the tree stand, which was artificially introduced on lands previously used for farming, was accepted as an ecosystem on the former farmland. A total of 36 trees from 12 areas were chosen for the comparisons, where six areas contained former farmland and six contained forest land. The compared tree stands differed from each other only in terms of the growth conditions, *i.e.*, forest and former farmland soils. Selected properties and characteristics of the tree tissue, including density, bending strength, wood static compression, thickness of the cell wall, and lignin content in the dry mass, were subject to analysis. The conducted research found significant differences in the analyzed variables between the compared tree groups. The pines grown on former farmland soil were characterized by a generally poor technical wood quality, thinner tracheid walls, and lower lignin content.

Keywords: Former farmlands; Scots pine; Properties of wood; Cell wall thickness; Lignin content

*Contact information: a: Poznan University of Life Sciences, Forest of Faculty, Department of Forest Utilisation, Wojska Polskiego 71A, 60-625 Poznań, Poland; b: Adam Mickiewicz University of Poznan, Faculty of Biology, Department of Plant Ecophysiology, Umultowska 89, 61-614 Poznań, Poland; c: Poznan University of Life Sciences, Forest of Faculty, Department of Forest Pathology, Wojska Polskiego 71C, 60-625 Poznań, Poland; d: Poznan University of Life Sciences, Forest of Faculty, Department of Forest Management, Wojska Polskiego 71C, 60-625 Poznań, Poland; e: Poznan University of Life Sciences, Forest of Faculty, Department of Forest Entomology; Wojska Polskiego 71C, 60-625 Poznań, Poland; *Corresponding author: tomasz.jelonek@up.poznan.pl*

INTRODUCTION

The economic performance of a product depends not only on the quantity, but chiefly on the quality. Numerous factors are significant to determine the effectiveness of forest productivity as well as in the final timber quality. The final effect on timber production is decided largely by the characteristics that result, to a varying degree, from the growth and development conditions, as well as from human activity (Prescher and Ståhl 1986). Together with the genotype, these conditions are crucial in the process of tree tissue formation. From the viewpoint of forest and timber management, these factors shape quality and value (Brüchert *et al.* 2000; Jelonek *et al.* 2010).

The constant increase in the global demand for wood may cause a deficit in the near future. According to FAO (2000), when the world population reaches 10 billion people, which may happen in the first half of the 21st century, the mean wood demand is predicted to rise to 0.6 m^3/person/year (equal to 2.4 m^3/person in the USA). The amount of wood worldwide will be over 6 billion m^3, which is approximately 2 billion m^3 less than the demand.

One of the methods to intensify the production of wood pulp is the use of land that previously has been used for agricultural purposes. Roughly 5 million ha of new areas are afforested every year worldwide. The total forest area in the world is about 4 trillion ha (FAO 2015). Furthermore, the average forest cover in countries around the world (in relation to the land area) reaches 31%. Therefore, 0.62 ha of forests is vested per one person on Earth. According to the FAO (2015) the greatest afforestation rate is in Asia (China), and it amounts to 5 million ha/year. Meanwhile, the afforestation rate in Europe is 170 000 ha/year. Oceania with 59 thousand ha/year has the lowest afforestation rate, whereas South America has a rate of 104 thousand ha/year. China afforests 1.5 million ha each year using barren vegetation and farmlands to start tree plantations that mainly consist of eucalyptus, poplar, and pine trees (FAO 2015).

Between 1998 and 2007, afforestation and reforestation made a substantial impact on the development of forest resources. At the global level, afforestation measures have helped, along with the natural expansion of forests in some countries and regions, to reduce the net loss of forest area to 8.3 million ha/year in the 1990s and to 5.2 million ha/year in the last decade, which is lower compared with the gross loss rate through deforestation and natural causes of 16 million ha/year in the 1990s and 13 million ha/year in the last decade (FAO 2015).

Even though the problem of afforestation on a global scale has been a subject of discussion since 1940s (Nature 1948), the issue of forests on former farmland areas is still one of the most crucial problems in modern forestry. Furthermore, the question of obtaining wood from tree stands grown on former farmland remains unanswered. The afforestation process of former farmlands has for a long time been considered to be a reservoir of wood energy as well as a tool to limit destructive wind activity. Contemporarily afforested former farmlands have environmental (protective), social, and productive functions. The role of former farmland in the creation of new forest phytocoenoses encourages the development of new strategies for the afforestation process of former farmlands. The issue of afforestation of former farmland is touched upon numerous times in the literature. The most prominent topic of research concerns the ecological aspects and carbon sequestration aspects of afforestation (Masera *et al.* 2003; García-Quijano *et al.* 2007; Kurbanov *et al.* 2007; Vesterdal *et al.* 2007). Publications pertaining to the planning and shaping of afforestation are less frequent (Ginsberg 2002; Gusti 2007). The issues pertaining to the quality of wood produced on former farmland have been studied sporadically (Hytönen 2003).

This paper compares the characteristics and properties of tree tissue grown on former farmland with those grown on in typical forest land. This work addresses the hypothesis that the wood produced in tree stands grown in former farmlands is different from wood produced on soil characteristic for forest conditions.

EXPERIMENTAL

The research procedure was set up in Poland in regions with a large percentage of mature tree stands grown on former farmland in the first generation. The experiment was conducted in mature tree stands of Scots pine (100 years old, +/- 5 years) because the age and size of trees in cutting age enable to observe possible changes in the properties and the structure of wood, which can result from tree tissue formation processes as well as functioning of trees in determined growth conditions.

The research encompassed 36 pine trees from 12 tree stands located in six forest divisions (Fig. 1 and Table 3). The research was performed on economic pine tree stands aged roughly 100 years grown on former farmland (P) and in forest land (L).

The tree stands chosen for the scrutiny were similar to each other concerning growth conditions such as habitat or density. Furthermore, the stands were also similar with respect to biometric features such as diameter at breast height (DBH) and tree height (Table 1). Between DBH and tree height (H) growing on former farmland and forest soil, no statistically significant differences were noticed (Table 2)

Table 1. Statistical Characteristics of Trees Growing on Former Farmland (P) and Forest Soils (L)

Biometric features	Type of soil	N	Mean	Median	Minimum	Maximum	Stand. dev.	Coefficient of variability [%]
H [m]	L	18	24.35	23.95	20.40	29.50	2.70	11.10
	P	18	24.43	24.60	21.00	29.50	2.14	8.74
	generally	36	24.39	24.25			2.40	9.85
$D_{1,3}$ [cm]	L	18	32.13	32.00	20.50	45.00	6.18	19.23
	P	18	33.56	33.00	21.50	49.00	7.47	22.25
	generally	36	32.84	32.00			6.79	20.68

Table 2. Analysis of Variance of Biometric Traits of Trees Growing on Former Farmland (P) and Forest Lands (L)

Biometric features	SS	df	MS	SS	df	MS	F	p
H [m]	0.05444	1	0.05444	201.761	36	5.93415	0.009175	0.924254
$D_{1.3}$ [cm]	18.34694	1	18.34694	1596.541	36	46.95708	0.390717	0.536096

** Differences are statistically significant at $p<0.05$*

This work employed both natural and dendrometric methods of choosing sample trees, as developed by Kraft (Kraft 1884) and Urich according to which in each tree stand a 1-ha research area was established. In the first phase, the tree stand was classified following Kraft's class categorization (1884). Next, the trees in each research area were divided into three density degrees according Urich's method (Van Laar and Akça 2007). For this reason, on each sample area all trees had their diameter at breast height and their height measured. Based on the thickness and height characterization, an average tree from each class was selected, which together constituted a total of 36 model trees, 18 trees grown on former farmland tree stands, and 18 from tree stands grown on forest soil. Such a combination of dendrometric method and natural classification ensures following the same plan for selecting trees on all research areas and eliminating the subjectivity of Kraft's classification. Selected Scots pines had no visible flaws, they had symmetrically shaped crowns, and they were characterized as being in good health. Thirty-six model trees were felled, and from which the material was collected in order to analyse chosen physical and mechanical properties of wood. The material for laboratory analysis came from 50-centimeter long bolts collected from 1.30 to 1.80 m away from the back cut plane (A) and next from the middle of the trunk (B) and the live base crown (C) (Fig. 2).

Furthermore, in each tree model (out of 36 models considered), the structure of the wood tissue, *i.e.*, the thickness of the tracheid walls (Fig. 3), as well as the lignin content in the tracheid walls, was analyzed.

In order to establish the thickness of cell walls and the lignin content from each felled sample tree collected from the height of 1.3 m (DBH), there were 10 samples from a part encompassing the last 10 annual diameter increments (5 samples from northern part of the trunk and 5 samples from the southern part). In addition, each of the collected samples underwent an analysis which was repeated three times.

Fig. 1. Location of the research areas

Table 3. Research Areas

Forest Division	Year	Type of soil	Location
Warcino	2014	L	N 16° 99' 12", E 55° 17' 15"
		P	N 17° 00' 10", E 54° 19' 12"
Trzebielino	2014	L	N 57° 08' 13", E 17° 09' 43"
		P	N 54° 14' 48", E 17° 01' 46"
Olesno	2014	L	N 50° 56' 53", E 18° 24' 30"
		P	N 50° 56' 54", Eº 18° 24' 16"
Drawsko	2014	L	N 15° 53' 30", E 53° 27' 07"
		P	N 15° 53' 27", E 53° 27' 04"
Kaczory	2014	L	N 53° 10' 12", E 16° 49' 11"
		P	N 53° 9' 21", E 16° 47' 13"
Szczecinek	2015	L	N 53° 77' 10", E 16° 91' 09"
		P	N 53° 46' 05", E 16° 53' 06"

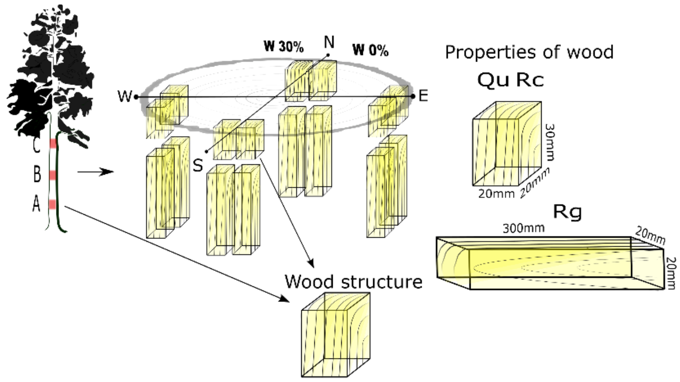

Fig. 2. Schematic presenting material collection

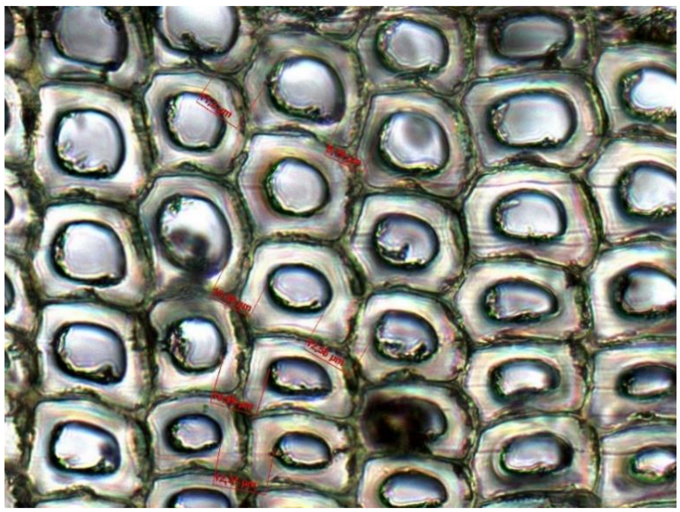

Fig. 3. Measurement of the cell wall diameter of the tracheids (late wood)

The wood properties were analyzed on twin samples with two moisture content levels, *i.e.*, absolutely dry and above the fiber saturation point (30% saturation). The collected samples, in the form of 50-cm long bolts from the trunk, were turned into small bars 20 x 20 mm in cross-section, and next they were divided in 30-centimeter fragments intended for testing static bending durability (R_g) and 3-centimeter fragments for conventional density testing (Q_u) and the strength of compression along the fibers (R_c). The samples were collected in four directions N-S and E-W in two adjacent rows (Fig. 2). These were twin samples free of any visible flaws and intended to test wood properties on two levels of moisture content (0% ≥ 30%).

Wood density was evaluated using a stereometric method, and it was determined as conventional density,

$$Q_u = \frac{m_o}{V_{max}} \left[\frac{kg}{m^3}\right] \tag{1}$$

where m_0 is the mass of a sample in completely dry matter (kg), and V_{max} is the volume of the sample in maximal expansion (m^3). Static bending strength and compression along the fibers strength were determined with a universal testing machine by adopting appropriate formulas,

$$R_g = \frac{3\ x\ P_{max}\ x\ l}{2\ x\ b\ x\ h^2}\ [\ MPa] \quad (2)$$

where P_{max} is the maximum (destructive) compressive stress (N), l is the spacing of the supports (mm), b is the width of the sample (mm), and h is the height of the sample (mm).

$$R_C = \frac{P_{max}}{A}\ [\ MPa] \quad (3)$$

In Eq. 3, P_{max} is the maximum (destructive) compressive stress (N), and A is the cross-sectional area of the sample (cm^2).

The lignin content was determined spectrophotometrically (with 10 repetitions were done for each tree) following the method of Doster and Bostock (1988) with certain modifications described in detail by Jelonek *et al.* (2017). In brief, the method focused on the last 10 annual rings, which were treated with methanol for 48 h (1 mL of methanol per 1 g of wood tissue). After drying the wood, 10 mg of dry tissue was mixed with 2.5 mL of 2N HCl and 0.25 mL of thioglycolic acid. The final precipitate was dissolved in 2.5 mL of 0.5N NaOH, and the absorbance was measured at 280 nm using a UV-1202 Shimadzu spectrophotometer. The lignin content was presented in relative units (U) per 10 mg of dry matter. The process was repeated 5 times for each sample. The measurement of the cell wall thickness was done in the middle of the radial wall by using pictures taken with an AxioCam MRc5 camera (Zeiss, produced in Oberkochen, Germany) and working with AxioVision software (Zeiss). The process was similar to that adopted by Seo *et al*. (2012).

At the onset of the mathematical-statistical stage the main focus was put on determining characteristic features of the changeable groups and on the choice of appropriate tests. Statistics (descriptive) were of pivotal importance for the analysis and data presentation. Among the adopted terms were the mean (average), maximum, minimum standard deviation, and coefficient of variation. The variables were distributed similarly to the normal ones in order to verify the differences between the groups; variance analyzes and parametrical tests of significance were conducted a parametrical significance test (NIR and Tukey's RIR). The statistical analysis was done with the use of Statistica 12.0 package software (StatSoft, Tulsa, OK, USA).

RESULTS

Initially, the mean wood properties were compared, *i.e.* the basic density (Q_u), compression strength along the fibers (R_c), as well as static bending strength (R_g) of the wood with two different moisture contents (0% and ≥ 30%).

Properties

Wood density

The mean basic density value of the pine wood was 421 kg/m^3, with the median at 417 kg/m^3 and the coefficient of variation at 14% (Table 4). The density ranged between 386 kg/m^3 and 453 kg/m^3, with the coefficient of variation between 11% and 15%. Forest trees were of notably higher density (435 kg/m^3), with a significance test level of p less than 0.01 and higher coefficient of variation (14%). These values were determined from the trees grown in forest land compared with the pine wood from former farmland. In this case, the mean basic wood density was at 407 kg/m^3, and the coefficient of variation was 13% (Table 4).

Table 4. Statistical Characteristics of Basic Density of the Wood Grown on Former Farmland and on Forest Lands

Type of soil	N	Mean (kg/m^3)	Standard dev. (kg/m^3)	Minimum (kg/m^3)	Maximum (kg/m^3)	Median (kg/m^3)	Coefficient of variation (%)
L	921	435.04**	56.99	287.00	713.00	431.88	13.10
P	923	407.35**	57.64	236.55	745.92	402.46	14.15
Total	1846	420.67	58.95	236.55	745.92	416.55	14.01

** Differences are statistically significant at $p < 0.01$

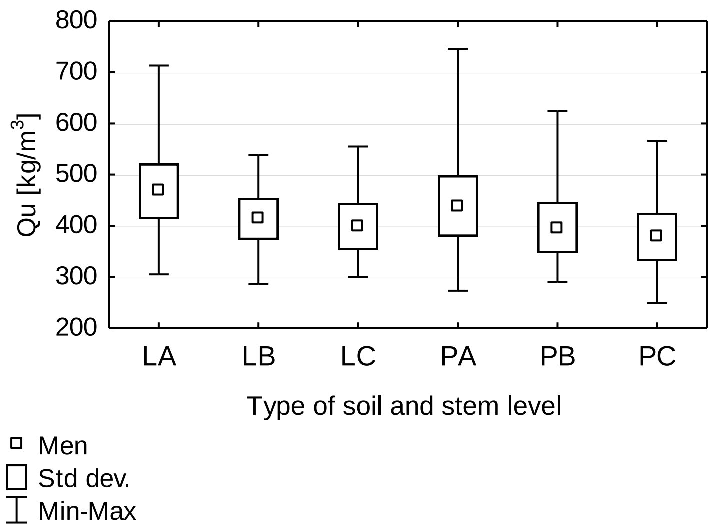

Fig. 4. Statistical characteristics of basic density of the wood grown on former farmland and on forest land

The next step was the analysis of the basic density in the vertical distribution on the full bole. In the tree stands grown on former farmland and on forest land, the significantly highest values of the mean and median densities were determined at the diameter at breast height, while the lowest were at the base of the tree crown (Fig. 4). Moreover, the highest variance of the density was established in the lower section of the full bole. The coefficient of variation at this level was 13.5% in the P group and 11.6% in the L group. The density gradually decreased with the height and dropped to minimum at the base of the crown.

The wood density at the A level was over 11% higher than the density at the B level, and it was almost 15% higher than the density at the C level for the wood from the trees grown in forest land ($p < 0.05$). These differences were lower in the case of the trees grown on former farmland, and they amounted to 9.5% and 13.9%, respectively. Relatively small differences were ascertained between the B and C levels, which equaled 3.6% in the L group and 4.8% in the P group.

The pines from the tree stands grown on forest land were characterized by significantly higher densities at each of the three analyzed levels (A, B, and C) compared with the trees grown on former farmland. However, no significant differences in the wood density of the trees grown in forest land between the middle of the purified full bole (414 kg/m^3) and base of the live crown (399 kg/m^3) were determined. Furthermore, no significant differences concerning density were determined between the middle of the full bole (394 kg/m^3) for the trees from former farmland and the base of the crown (399 kg/m^3) for the trees grown on forest land (Fig. 4).

Compression strength along the fibers

The mean compression strength of the saturated wood was 19.9 MPa for the trees grown on forest land. This value was significantly higher than the strength of the pine wood grown on former farmland, which had a mean value of 18.3 MPa (Fig. 2). The strength of the absolutely dry wood was higher in the wood from trees grown on forest land (62.1 MPa) compared with the wood from former farmland (54.2 MPa). The coefficients of variation of the analyzed property were similar to each other in the compared tree groups and reached 20% for the dry wood and between 27% and 29% for the saturated wood (Table 5).

Table 5. Statistical Characteristics of Compression Strength along the Grain in the Saturated and Absolutely Dry Wood

	Type of soil	N	Mean (MPa)	Standard dev. (MPa)	Minimum (MPa)	Maximum (MPa)	Median (MPa)	Coefficient of variation (%)
$R_{c0\%}$	L	901	19.88**	3.99	2.83	35.19	19.35	20.06
	P	878	18.33**	3.69	7.22	33.62	18.00	20.11
	Total	1790	19.11	3.92	2.83	35.19	18.68	20.49
$R_{c30\%}$	L	879	62.13**	17.02	20.91	127.54	62.57	27.40
	P	900	54.18**	15.74	10.63	102.89	52.88	29.05
	Total	1779	58.10	16.86	10.63	127.54	57.83	29.01

$R_{c30\%}$ - compression strength in the wood with moisture content exceeding the saturation point (30%); $R_{c0\%}$ - compression strength of the absolutely dry wood; ** Differences are statistically significant at $p < 0.01$.

An analysis of the axial variability was conducted in order to compare both analyzed populations with the focus on the compression strengths along the fibers of the pine wood. The strength of the dry wood in the L group was higher by 15% at the A level than the strength determined at the B level. It was also 19% higher than the wood strength at the C level. In the case of the pines grown on former farmland, these values were 10% and 15%, respectively. Furthermore, the pines grown in forest land were characterized by strengths that were 15% higher at the A level, 9% higher at the B level, and 11% higher at the C level.

Smaller differences were ascertained in the strength of the saturated wood. There was an 11% difference in the trees grown on forest land between the A and B levels, 14% difference between the A and C levels, and 3% difference between the B and C levels. In the P tree group, these values were 7%, 15%, and 9%, respectively. The differences in the wood strength between the pines from the L and P groups measured 9% at the A level, 4% at the B level, and 10% at the C level in favor of the trees grown on former farmland.

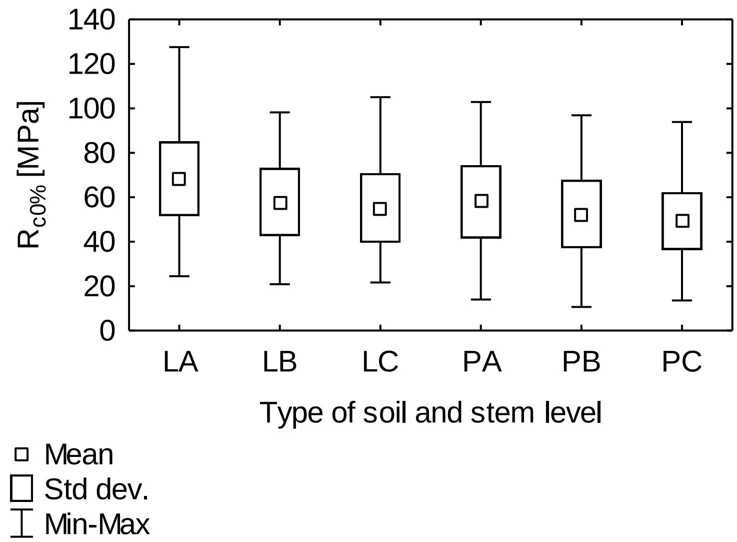

Fig. 5. Statistical characteristics of compression strength along the grain in absolutely dry wood from the trees grown on former farmland and on forest land

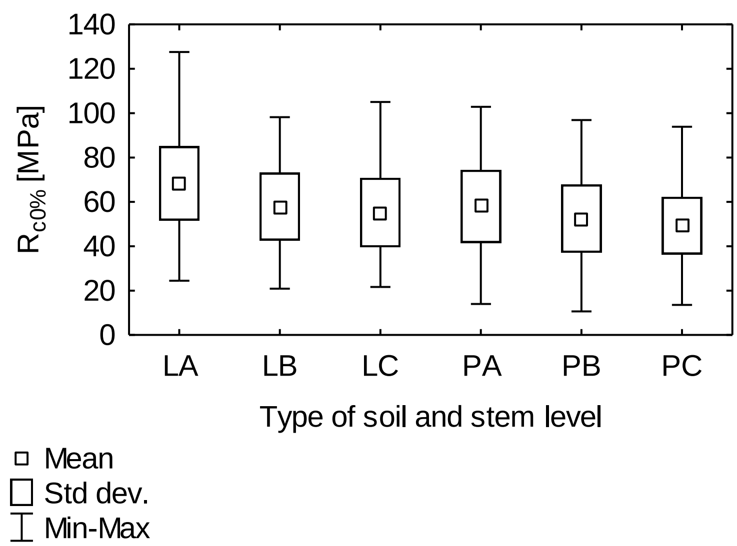

Fig. 6. Statistical characteristics of compression strength along the grain in the saturated wood from the trees grown on former farmland and on forest land

The highest compression strength along the fibers for both absolutely dry wood and saturated wood was in the pines grown on forest land at the A level. The mean strength at this height was 68 MPa and 21 MPa for the dry and saturated wood. It was 15% and 9% higher than those for the dry and saturated wood from the pines grown on former farmland, respectively (Figs. 5 and 6). Significant differences in the strength also occurred in the saturated wood between the A level as well as the B and C levels in the wood from the trees grown on former farmland. In the absolutely dry wood, significant differences were also determined between the B level in the trees from the L group, the A level of the pines from the P group, and the B and C levels in the P group. The highest compression strength was determined at the A level in both the trees grown on former farmland and on forest land, while the lowest was present at the C level. However, these values were not significantly different from the maximum wood strength, which was found at the B level.

Static bending strength

The analysis of the static bending strength of the wood (R_g) was conducted similarly to the analysis of the compression strength along the fibers. The mean bending strength of the saturated wood was 51.2 MPa in the trees grown on forest land. It was also significantly higher ($p<0.01$) than the strength of the wood from the pines grown on former farmland, which was 45.2 MPa (Tab. 4). Similarly to the strength of the saturated wood, the strength of absolutely dry wood was significantly higher ($p<0.01$) in the wood from the trees grown on forest land (103.69 MPa) when compared with that grown on former farmland (91.1 MPa). The median of the strength was close to the mean, which indicated a symmetric distribution of the compared populations. Even though the standard deviations were significantly higher for absolutely dry wood (from 26 MPa to 32 MPa) than for saturated wood (from 12 MPa to 13 MPa), the coefficients of variation were comparable. Furthermore, their values were about 30% for both groups (Table 6).

Table 6. Statistical Characteristics of Static Bending Strength in Saturated and Absolutely Dry Wood

	Type of soil	N	Mean (MPa)	Standard dev. (MPa)	Minimum (MPa)	Maximum (MPa)	Median (MPa)	Coefficient of variation (%)
$R_{g30\%}$	L	763	51.24**	13.38	7.18	101.9	50.26	26.11
	P	795	45.14**	12.1	7.39	99.92	44.34	26.80
	Total	1558	48.13	13.1	7.18	101.9	47.33	27.22
$R_{g0\%}$	L	747	103.69**	31.58	13.22	213.99	102.62	30.45
	P	790	91.07**	26.16	12.99	225.77	91.16	28.72
	Total	1537	97.2	29.59	12.99	225.77	95.61	30.44

$R_{g30\%}$ - static bending strength in the wood with a moisture content above the saturation point (30%); $R_{g0\%}$ - static bending strength in the absolutely dry wood; ** Differences are statistically significant at $p<0.01$

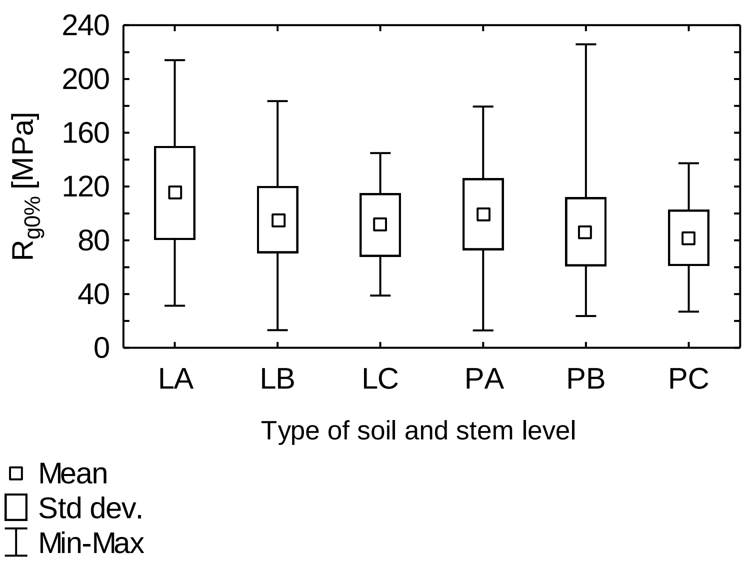

Fig. 7. Statistical characteristics of static bending strength along the grain in absolutely dry wood from the trees grown on former farmland and on forest lands

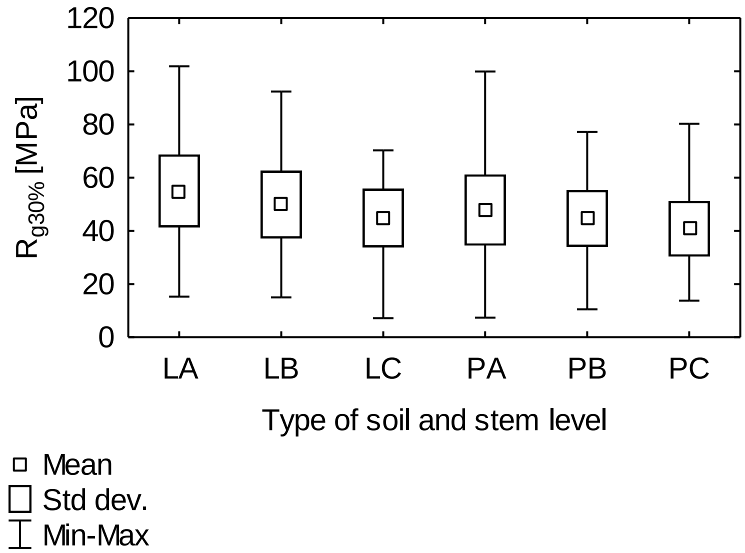

Fig. 8. Statistical characteristics of static bending strength along the grain in saturated wood from the trees grown on former farmland and on forest lands

Subsequently, an analysis was performed of the static bending strength in the axial distribution of the trunk. Similarly to the compression strength, the mean bending strength decreased higher up the full bole. The significantly highest strengths of the absolutely dry (115.2 MPa) and saturated wood (55.0 MPa) were determined at the A level in the trees grown on forest land (Figs. 7 and 8).

The significantly highest strengths for both moisture contents were determined at the A level in the trees that grew on forest land. However, the significantly lowest values of the wood strength were found at the C level in the trees grown on former farmland. The only exception was the strength at the B level of the dry wood from the pines grown on former farmland. It did not differ significantly from the highest strength, which was found at the C level (Figs. 7 and 8). The variability in the analyzed strength ranged from 24% to 30%. In the case of the dry wood strength, it was highest at the A level in the trees grown on forest land. However, the highest variability in the strength of the saturated wood was detected at the A level, apart from the trees from the P group (Fig. 8).

Cell wall thickness of tracheids

The cell wall thickness of the tracheids was analyzed in the late and early wood with the two moisture contents, *i.e.*, dry and saturated. The results of this analysis for the late wood are presented in Table 5. The cell wall thickness of early wood in the compared groups was similar. The mean was 2.1 µm ± 0.35 µm in dry wood and 5.0 µm ± 0.76 µm in saturated wood. On average, the difference between the thickness of the tracheid walls of dry and saturated woods was approximately 58% for both pine groups. This meant that the tracheid walls in the dry wood were thinner by more than half compared with the tracheids in the saturated wood. Smaller differences were noted for the late wood, where the tracheid walls in the dry wood were thinner by 22% compared with the saturated wood from the pines grown on forest land and by 28% for the trees grown on former farmland.

Because the thickness of the tracheid walls of the early wood did not vary significantly between the compared groups, the results were omitted. Furthermore, the analysis concentrated on the thickness of the tracheid walls of the late wood. The mean tracheid wall thickness in this type of wood from the trees grown on forest land measured 9.34 µm in the saturated wood and 7.30 µm in the dry wood. These values were significantly higher than the mean tracheid thicknesses, which were measured in the wood from the trees grown on former farmland (8.88 µm and 6.38 µm, respectively) (Table 7).

Table 7. Statistical Characteristics of Cell Wall Thickness in Late Wood

Late wood	Type of soil	N	Mean (µm)	Standard dev. (µm)	Minimum (µm)	Maximum (µm)	Median (µm)	Coefficient of variation (%)
Wet	L	360	9.34*	2.46	3.48	15.51	9.53	26.34
	P	360	8.88*	1.53	4.83	14.86	8.88	17.21
	Total	720	9.11	2.56	3.13	15.51	8.98	28.10
Dry	L	360	7.30**	1.57	3.16	11.5	7.3	21.44
	P	360	6.38**	1.44	3.42	10.32	6.44	22.63
	Total	720	6.85	1.57	3.16	11.5	6.82	22.98

* Differences are statistically significant at $p<0.05$; ** Differences are statistically significant at $p<0.01$.

Lignin content in the dry matter

An analysis of the lignin content in the dry matter of the tree tissue was also performed. The mean lignin content was 0.820 U/10 mg of dry wood matter. Furthermore, it ranged from 0.723 U/10 mg to 0.997 U/10 mg in the wood from the trees grown on forest land, as well as from 0.725 U/10 mg to 0.922 U/10 mg in the wood from the trees grown on former farmland. The conducted analysis of variance pointed to a statistically significant difference between the lignin content in the trees grown on former farmland and forest land. A significantly higher lignin content ($p = 0.023$) of 0.823 U/10 mg was determined in the tree tissue of the trees grown on forest land. When compared to the wood from the trees grown on former farmland, this content amounted to a mean of 0.807 U/10 mg, and it was lower by 3.12% (Table 8).

Table 8. Statistical Characteristics of the Lignin Content in Wood from the Trees Grown on Forest Lands and Former Farmland

	Type of soil	N	Mean (U/10 mg)	Standard dev. (U/10 mg)	Minimum (U/10 mg)	Maximum (U/10 mg)	Median (U/10 mg)	Coefficient of variation (%)
Lignin content	L	180	0.833*	0.072	0.723	0.997	0.796	8.68
	P	180	0.807*	0.043	0.725	0.922	0.791	5.35
	Total	360	0.820	0.060	0.723	0.997	0.793	7.32

* Differences are statistically significant at $p<0.05$.

DISCUSSION

The function of trees in physiological terms, together with the formation of the tree tissue, were described by Zobel and van Buijtenen (1989) and Chaffey (2002). Furthermore, Zobel and van Buijtenen (1989) presented a comprehensive description of the variability in wood at a cellular level. It is well known that the properties of wood tend to evolve in ways that enhance the survival of the trees. The resulting evolution of wood characteristics affect the tree's functions and growth. That is why the wood characteristics include a complex chemical composition and anatomical structure, which is specific to a given species and from which the physical and mechanical properties of the wood directly are derived (Pereira *et al.* 2003).

Selected wood characteristics and properties were compared in this work. Comparisons were made between trees grown on former farmland for the first generation and on forest land. These analyses focused on the basic density, static bending strength, and compression strength along the wood fibers. Also, structural characteristics of the tree tissue were tested, *i.e.*, cell wall thickness and lignin content in the dry matter.

First, one of the most frequently measured physical properties of wood, *i.e.*, density, was subjected to analysis. It is a relatively well examined property in the case of pine. A literature review of this subject reveals numerous studies describing wood density and its relationship to the features which shape the conditions for growth and development of both trees and tree stands (Lindström 1996; Herman *et al.* 1998; Saranpää 2003; Auty *et al.* 2014; Zeller *et al.* 2017). However, there are no characteristic features which can be found on former farmlands.

The wood density of the researched trees ranged from 386 kg/m^3 to 453 kg/m^3; for the dry wood, the R_c ranged from 11 MPa to 125 MPa, and the R_g ranged from 13 MPa to 226 MPa. In the case of saturated wood, the R_c ranged from 14 MPa to 24 MPa and the R_g ranged from 7 MPa to 102 MPa. Such a significant discrepancy between the results can be probably connected to the influence of the natural heterogeneity of the tree tissue on its molding (Thörnqvist 1993).

It should also be emphasized that in the case of the trees grown on former farmland a significantly lower tree tissue density was determined, which was 407 kg/m^3 ± 58 kg/m^3. This value could be compared to the mean density of the wood from the trees grown on forest land, where the mean density was 435 kg/m^3 ± 57 kg/m^3. This confirmed one issue, which had been frequently emphasized by forest practices. Namely, there is a distinctness in timber from the tree stands grown on former farmland when compared with the wood from the tree stands grown on typical forest land.

The gradual decrease in wood density with an increase in height (measurement on the full bole) in coniferous trees should be considered to be a rule (Koch 1972; Zobel and van Buijtenen 1989; Persson *et al.* 1995). A similar rule pertains to other technical parameters of wood, including mechanical properties (Pazdrowski 1992; Jelonek *et al.* 2010; Tomczak and Jelonek 2012). Zobel and Talbert (2003) concluded that the main cause of variability in the properties of coniferous wood species was due to the presence of juvenile wood and its proportion to mature wood. This is closely connected to the variability of the late wood percentage in growth rings (Kellogg and Wangaard 1969; Wimmer 1995).

The differentiation of wood properties inside the full bole of pine has been described by Machado and Cruz (2005). A gradual decrease in the mechanical wood properties was ascertained in the direction from the base of the full bole to the top. This was consistent with the obtained results in the present work. In the axial distribution of the pine wood grown on forest land, the properties were higher with each of the analyzed levels (A, B, and C) compared with the properties of the tree tissue from the trees grown on former farmland. The obtained results confirmed the influence of former farmland on molding the pine tree tissue. Its wood, compared with wood from trees grown in forest land, was characterized by poor technical quality. This pertained to the whole length of the full bole, as well as to the sphere of both large- and medium-sized raw material. This significant decrease in wood properties in the trees grown on former farmland should, as a consequence, contribute to a change in attitude towards the management of tree stands growing in these atypical conditions.

The influence of wood ultrastructure on mechanical properties is often emphasized in the literature (Löve 1972; Fengel and Wegener 1983; Zimmermann 1983; Bendtsen and Senft 1986; Gu *et al.* 2001; Hématy and Höfte 2006). The tissue walls of wood from coniferous species are a macromolecular conglomerate. Its main elements are cellulose and lignin (Blanchette 1993). The changes in the amount of the basic components of the cell wall can change in a species depending on the growth and development conditions, genetic conditions, and tree age (Zobel 1971; Fengel and Wegener 1983; Lewin and Goldstein 1992; Fujita and Harada 2000). The conducted research fits into the thesis mentioned above. A difference in the tracheid wall thickness of the late wood was established between the compared populations. The mean thickness of the tracheid walls of the late wood was approximately 9 µm in the saturated wood and 6.5 µm in the dry wood. This is consistent with the results given for this species in the literature (Verkasalo 1992; Hannrup *et al.* 2001; Martín *et al.* 2010). The tracheid walls of the late wood are significantly thicker for both the saturated and dry wood. The difference in the thickness was 5% and 13% for saturated and dry wood, respectively, from trees grown on forest land compared with the pines grown on former farmland. Larger differences were observed in the pines grown on former farmland between the thickness of the tracheid walls of the late wood that were saturated and dry. These differences also point to a difference in the chemical construction of the wood between the two tree groups. The larger swelling of the tracheid walls in the pines grown on former farmland indicated a relatively larger hydrophilic amorphous cellulose content compared with the wood grown on forest land. This probably has had a direct influence on the properties of the tree tissue depending on moisture content. This seems particularly relevant when using wood for construction purposes.

Significant differences in lignin content in the dry wood pulp were determined between the studied groups. The lignin content was over 3% higher in the trees grown on forest land than in the trees grown on former farmland. The difference was statistically significant. The chemical components of the tissue wall, as well as their distribution, significantly determine both mechanical and physical properties of the wood. Lignin is, first and foremost, responsible for the compression strength of wood. An increase in the lignin content in wood tissue increases the resistance of cell walls to deformation and ensures its mechanical stability (Boudet *et al.* 1995; dos Santos Abreu *et al.* 1999). Moreover, lignin facilitates the transportation of water and impedes the degradation of polysaccharide walls. Their activity can be described as antiseptic in relation to pathogenic factors (Monties 1989; Hatfield and Vermerris 2001).

Growth conditions for the trees grown on former farmland influenced the occurrence of changes in the tree tissue construction. These differences in the wood structure between the discussed groups may have taken place due to adaptive changes. The changes stem directly from the overlapping physiological and mechanical systems, which have already been emphasized by Schniewind (1962). These adaptive changes, pertaining mainly to the tree anatomy, are multifunctional in coniferous species and they determine the remaining characteristics and properties of tree tissues. Consequently, this has led to the creation of the tree tissue model, which is characteristic for former farmland.

CONCLUSIONS

1. Significant differences between the studied wood properties were determined in all of the compared groups. Significantly higher tree tissue properties were determined in the case of the pines grown on forest land compared with the trees grown on former farmland. The pine wood grown on former farmland was characterized by a significantly lower basic wood density (of 6%) compared with that of trees grown on forest land. In contrast, as far as the static bending strength is concerned, the differences amounted to 12% for the strength for both moisture contents. The differences in the compression strength along the fibers were approximately 8% for the saturated wood and 13% for the dry wood. Moreover, a change in the wood moisture content in the extreme ends of the hygroscopic range caused a double change in the static bending strength and a triple change in the compression strength along the fibers. These changes stemmed from the chemical and submicroscopic construction of the wood. They also pointed to a significant effect on the strength by the moisture content.
2. The wood from the trees grown on former farmland was characterized by significantly thinner tracheid walls and a lower lignin content. The tracheids in the late wood zone in the pines grown on former farmland were thinner by 5% in the saturated wood and 13% in the dry wood. Moreover, the pine wood from these pines had 3.12% less lignin content than the wood from the trees grown on forest land.
3. The axial and radial variabilities of the analyzed properties of wood were determined. All of the analyzed properties decreased in the direction from the base of the stem to its top in the axial distribution. In the majority of cases, the aforementioned differences were significantly higher at each of the studied levels in the wood from the trees grown on forest land.
4. An analysis of selected elements of wood structure and properties was consistent with the idea that formation of tree tissue has adaptive characteristics for the growth and development conditions of trees. The tree structure determines the properties of tree tissue, which create a closed system of dependence.

ACKNOWLEDGMENTS

The publication is co-financed within the framework of Ministry of Science and Higher Education programme as "Regional Initiative Excellence" in years 2019-2022, project number 005/RID/2018/19

REFERENCES CITED

Auty, D., Achim, A., Macdonald, E., Cameron, A. D., and Gardiner, B. A. (2014). "Models for predicting wood density variation in Scots pine," *Forestry* 87(3), 449-458. DOI: 10.1093/forestry/cpu005

Bendtsen, B. A., and Senft, J. (1986). "Mechanical and anatomical properties in individual growth rings of plantation-grown eastern cottonwood and loblolly pine," *Wood Fiber Sci.* 18(1), 23-38.

Blanchette, R. A. (1993). "Reviewed work: *Wood Microbiology: Decay and Its Prevention* by Robert A. Zabel, and Jeffrey J. Morrell," *Mycologia* 85(5), 874-875. DOI: 10.2307/3760624

Boudet, A. M., LaPierre, C., and Grima-Pettenati, J. (1995). "Biochemistry and molecular biology of lignification," *New Phytol.* 129(2), 203-236. DOI: 10.1111/j.1469-8137.1995.tb04292.x

Brüchert, F., Becker, G., and Speck, T. (2000). "The mechanics of Norway spruce [*Picea abies* (L.) Karst.]: Mechanical properties of standing trees from different thinning regimes," *Forest Ecol. Manag.* 135(1-3), 45-62. DOI: 10.1016/S0378-1127(00)00297-8

Chaffey, N. (2002). *Wood Formation in Trees: Cell and Molecular Biology Techniques*, Taylor & Francis, London, United Kingdom.

dos Santos Abreu, H., do Nascimento, A. M., and Maria, M. A. (1999). "Lignin structure and wood properties," *Wood Fiber Sci.* 31(4), 426-433.

Doster, M. A., and Bostock, R. M. (1988). "Quantification of lignin formation in almond bark in response to wounding and infection by *Phytophthora* species," *Phytopathology* 78(4), 473- 477. DOI: 10.1094/phyto-78-473

FAO (2000). *Global Forest Resources Assessment 2000* (FRA 2000), Food and Agricultural Organization of the United Nations (FAO), Rome, Italy.

FAO (2015). *Global Forest Resources Assessment 2015. How are the World's Forests Changing?*, Food and Agricultural Organization of the United Nations (FAO), Rome, Italy.

Fengel, D., and Wegener, G. (1983). "Structure and ultrastructure," in: *Wood: Chemistry, Ultrastructure, Reactions*, De Gruyter, Berlin, Germany, pp. 6-25.

Fujita, M., and Harada, H. (2000). "Ultrastructure and formation of wood cell wall," in: *Wood and Cellulosic Chemistry*, D. N.-S. Hon and N. Shiraishi (eds.), Marcel Dekker, New York, NY, pp. 1-49.

García-Quijano, J. F., Peters, J., Cockx, L., van Wyk, G., Rosanov, A., Deckmyn, G., Ceulemans, R., Ward, S. M., Holden, N. M., Van Orshoven, J., *et al*. (2007). "Carbon sequestration and environmental effects of afforestation with *Pinus radiata* D. Don in the Western Cape, South Africa," *Climatic Change* 83(3), 323-355. DOI: 10.1007/s10584-006-9204-5

Ginsberg, P. (2002). "Planning and management of the afforestation process in Northern Israel," *New Forest.* 24(1), 27-38. DOI: 10.1023/A:1020523923551

Gu, H., Zink-Sharp, A., and Sell, J. (2001). "Hypothesis on the role of cell wall structure in differential transverse shrinkage of wood," *Holz Roh. Werkst.* 59(6), 436-442. DOI: 10.1007/s001070100240

Gusti, M. (2007). "Modeling afforestation and the underlying uncertainties," *Water Air Soil Poll.* 7(4-5), 475-482. DOI: 10.1007/s11267-006-9115-5

Hannrup, B., Danell, Ö., Ekberg, I., and Moëll, M. (2001). "Relationships between wood density and tracheid dimensions in *Pinus sylvestris* L.," *Wood Fiber Sci.* 33(2), 173-181.

Hatfield, R., and Vermerris, W. (2001). "Lignin formation in plants. The dilemma of linkage specificity," *Plant Physiol.* 126(4), 1351-1357. DOI: 10.1104/pp.126.4.1351

Hématy, K., and Höfte, H. (2006). "Cellulose and cell elongation," in: *The Expanding Cell*, J.-P. Verbelen and K. Vissenberg (eds.), Springer-Verlag Berlin, Heidelberg, Germany, pp. 33-56.

Herman, M., Dutilleul, P., and Avella-Shaw, T. (1998). "Growth rate effects on temporal trajectories of ring width, wood density, and mean tracheid length in Norway spruce (*Picea abies* (L.) Karst.)," *Wood Fiber Sci.* 30(1), 6-17.

Hytönen, J. (2003). "Effects of wood, peat and coal ash fertilization on Scots pine foliar nutrient concentrations and growth on afforested former agricultural peat soils," *Silva Fenn.* 37(2), 219-234. DOI: 10.14214/sf.503

Jelonek, T., Pazdrowski, W., Arasimowicz-Jelonek, M., and Tomczak, A. (2010). "Properties of wood of Scots pine (*Pinus Sylvestris* L.) growing on former farmlands," *Sylwan* 154(5), 299-311.

Jelonek, T., Pazdrowski, W., Tomczak, A., and Arasimowicz-Jelonek, M. (2017). "Lignification markers of the tracheid walls of scots pine (*Pinus sylvestris* (L.)) in various forms of dead bark," *BioResources* (12)2 3992-4003, DOI: 10.15376/biores.12.2.3992-4003

Kellogg, R. M., and Wangaard, F. F. (1969). "Variation in the cell-wall density of wood," *Wood Fiber Sci.* 3, 180-204.

Koch, P. (1972). *Utilization of the Southern Pines* (Agriculture Handbook No. 420), U.S. Department of Agriculture Forest Service Southern Forest Experiment Station, Washington, D.C.

Kraft, G. (1884). "Durchfarstungen Schlagstellungen und Lichtungshieben," in: *Beiträge zur Lehre*, Klindworth's Verlag, Hannover, Germany, pp. 18-58.

Kurbanov, E., Vorobyov, O., Gubayev, A., Moshkina, L., and Lezhnin, S. (2007). "Carbon sequestration after pine afforestation on marginal lands in the Povolgie region of Russia: A case study of the potential for a joint implementation activity," *Scand. J. Forest Res.* 22(6), 488-499. DOI: 10.1080/02827580701803080

Lewin, M., and Goldstein, I. S. (1992). *Wood Structure and Composition*, Marcel Dekker, New York, NY.

Lindström, H. (1996). "Basic density of Norway spruce. Part II. Predicted by stem taper, mean growth ring width, and factors related to crown development," *Wood Fiber Sci.* 28(2), 240-251.

Löve, Á. (1972). "Review: *Structure and Function of Trees* by M. H. Zimmermann, C. L. Brown," *Taxon* 21(2-3), 358-359. DOI: 10.2307/1218216

Machado, J. S., and Cruz, H. P. (2005). "Within stem variation of maritime pine timber mechanical properties," *Holz Roh. Werkst.* 63(2), 154-159. DOI: 10.1007/s00107-004-0560-4

Martín, J. A., Esteban, L. G., de Palacios, P., and Fernández, F. G. (2010). "Variation in wood anatomical traits of *Pinus sylvestris* L. between Spanish regions of provenance," *Trees* 24(6), 1017-1028. DOI: 10.1007/s00468-010-0471-4

Masera, O. R., Garza-Caligaris, J. F., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G. J., Pussinen, A., de Jong, B. H. J., and Mohren, G. M. J. (2003). "Modeling carbon sequestration in afforestation, agroforestry and forest management projects: The

CO2FIX V.2 approach," *Ecol. Model.* 164(2-3), 177-199. DOI: 10.1016/s0304-3800(02)00419-2
Monties, B. (1989). "Lignins," in: *Plant Phenolics*, J. B. Harborne (ed.), Academic Press, London, United Kingdom, pp. 113-157.
Nature (1948). "Afforestation as a world problem," *Nature* 161(4101), 902-903. DOI: 10.1038/161902b0
Pazdrowski, W. (1992). "Interdependence between the mean basic density and the strength of wood from butt logs of the Scots pine (*Pinus sylvestris* L.) as well as the density and the strength determined on different heights of the stem," *Sylwan* 136(1), 31-40.
Pereira, H., Graça, J., and Rodrigues, J. C. (2003). "Wood chemistry in relation to quality," in: *Wood Quality and its Biological Basis*, J. R. Barnett and G. Jeronimidis (eds.), Blackwell Publishing, Oxford, United Kingdom, pp. 53-86.
Persson, B., Persson, A., Ståhl, E. G., and Karlmats, U. (1995). "Wood quality of *Pinus sylvestris* progenies at various spacings," *Forest Ecol. Manag.* 76(1-3), 127-138. DOI: 10.1016/0378-1127(95)03557-q
Prescher, F., and Ståhl, E. G. (1986). "The effect of provenance and spacing on stem straightness and number of spike knots of Scots pine in South and Central Sweden," *Studia Forestalia Suecica* 172, 1-12.
Saranpää, P. (2003). "Wood density and growth" in: *Wood Quality and Its Biological Basis*, J. R. Barnett and G. Jeronimidis (eds.), Blackwell Publishing, Oxford, United Kingdom, pp. 87-117.
Schniewind, A. P. (1962). "Horizontal specific gravity variation in tree stems in relation to their support function," *Forest Sci.* 8(2), 111-118. DOI: 10.1093/forestscience/8.2.111
Seo, J.-W., Eckstein, D., and Jalkanen, R. (2012). "Screening various variables of cellular anatomy of Scots pines in subarctic Finland for climatic signals," *IAWA J.* 33(4), 417-429. DOI: 10.1163/22941932-90000104
Thörnqvist, T. (1993). *Juvenile Wood in Coniferous Trees* (Report No. IO), Swedish University of Agricultural Sciences, Department of Forest-Industry-Market Studies, Uppsala, Sweden.
Tomczak, A., and Jelonek, T. (2012). "Technical parameters of the juvenile and mature wood in Scots pine (*Pinus sylvestris* L.)," *Sylwan* 156(9), 695-702.
Van Laar, A., and Akça, A. (2007). *Forest Mensuration*, Springer, Dordrecht, The Netherlands.
Verkasalo, E. (1992). "Relationships of the modulus of elasticity and the structure of Finnish Scots pine wood," *Silva Fenn.* 26(3), 155-168. DOI: 10.14214/sf.a15644
Vesterdal, L., Rosenqvist, L., Van Der Salm, C., Hansen, K., Groenenberg, B.-J., and Johansson, M.-B. (2007). "Carbon sequestration in soil and biomass following afforestation: Experiences from oak and Norway spruce chronosequences in Denmark, Sweden and the Netherlands," in: *Environmental Effects of Afforestation in North-Western Europe*, G. W. Heil, B. Muys, and K. Hansen (eds.), Springer Dordrecht, Dordrecht, The Netherlands, pp. 19-51.
Wimmer, R. (1995). "Intra-annual cellular characteristics and their implications for modeling softwood density," *Wood Fiber Sci.* 27(4), 413-420.
Zimmermann, M. H. (1983). "Pathology of the xylem," in: *Xylem Structure and the Ascent of Sap*, Springer-Verlag Berlin, Heidelberg, Germany.

Zeller, L., Ammer, Ch., Annighöfer, P., Biber, P., Marshall, J., Schütze, G., Gaztelurrutiad, M., and Pretzsch, H. (2017). "Tree ring wood density of Scots pine and European beech lower in mixed-species stands compared with monocultures," *Forest Ecol. Manag.* 400, 363-374. DOI: 10.1016/j.foreco.2017.06.018

Zobel, B. (1971). "Genetic manipulation of wood of the southern pines including chemical characteristics," *Wood Sci. Technol.* 5(4), 255-271. DOI: 10.1007/bf00365059

Zobel, B., and Talbert, J. (2003). *Applied Forest Tree Improvement*, Blackburn Press, Caldwell, NJ.

Zobel, B., and van Buijtenen, J. P. (1989). *Wood Variations: Its Causes and Control*, Springer-Verlag Berlin, Heidelberg, Germany.

Article submitted: July 4, 2018; Peer review completed: September 9, 2019; Revised version received: February 19, 2019; Accepted: February 22, 2019; Published: March 4, 2019.
DOI: 10.15376/biores.14.2.3247-3265