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ORIGINAL RESEARCH ARTICLE

Radial variation in the wood properties of Scots pine (*Pinus sylvestris* L.) grown on former agricultural soil

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Abstract. The soil of former farmland greatly differs from forest soil, and significantly influences tree growth and development compared with other site factors. The effect may also be reflected indirectly in radial variability of wood. This study compared radial variation of wood density, compressive strength along the grain and static bending strength of wood of Scots pine trees growing on former farmland and forest soils. The analyses were conducted in eight mature pine stands. On the basis of the stand description, four stands were classified as growing on forest soil (L) and four as growing on former farmland soil (P). A total of 24 model trees were selected, twelve on each soil type. Analyses of wood properties were conducted along four axes from the cross sectional radius of the trees at breast height. Our analyses showed that radial variation in wood properties of Scots pine (from selected locations in Poland) growing on former farmland is similar to the variation among the control trees growing on forest soils. In both groups of trees, the lowest density and the lowest strength were in the pith (juvenile) zone. Wood with the highest density and greatest strength was located in the central part of the radius. Wood of Scots pine trees growing on former farmland soils in comparison to that of trees growing on forest soil was characterised by a statistically lower basic density, lower compressive strength along the grain and static bending strength.

Key words: basic density, static bending strength, compressive strength along fibers

1. Introduction

Coniferous species are characterised by variability of wood properties. In general, basic density and tree strength increase together with cambial age in the cross-section of a tree trunk (Kärenlampi, Riekkinen 2004). The phenomenon is connected with - inter alia - changes that occur in a macrostructure of wood. It is mainly a symptom of the maturation of the tree. Apart from tree age, varied environmental factors influence the process of forming wood tissue.

Former agricultural soil is a transformed ecosystem in which soil is exceptionally the non-forest element (Michalski et al. 2006). The soil changes under the influence of afforestation (Alriksson, Olsson 1995; Ritter et. al. 2003; Hagen-Thorn et. al. 2004), in particular its properties such as porosity, pH, and element content (Olszewska, Smal 2008; Smal, Olszewska 2008).

Soil is an important element of forest habitat that influences tree growth and development conditions; therefore, it has an influence on wood structure and properties. Forest site-type influences the amount of sapwood and heartwood, as well as mature and juvenile wood in a tree trunk (Jakubowski 2004). Pazdrowski i Spława-Neyman (1996) have observed that Scots pine wood, grown on varied forest site types, differs significantly on the basis of wood density, compressive strength along the grain, and static bending strength. Jelonek et al. (2005, 2008b, 2009) have worked on comparing wood properties of the Scots pine grown on

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former agricultural soil and those grown on forest soil. They have observed that comparing to wood obtained from trees grown on typical forest soil, wood obtained from the forest stand grown on former agricultural soil has been characterised by lower static bending strength and compressive strength along the grain at higher basic density. However, pines grown on forest soil have been characterised by wood of higher compressive strength along the grain and static bending strength (Jelonek et al. 2010).

In forestry practices, technical maturity of forest stands is equal to forest maturity. The forest stand, which reaches maturity, is characterised by proper quality and forest health. Its further growth is a time of its decay and progressive wood depreciation. Tomczak et al. (2009) have observed, analysing quantity changes in macrostructure of the tree that occurred during trees' aging, that Scots pine grown on former agricultural soil can reach technical wood maturity earlier. Jelonek et al. (2008a) had a similar observation while analysing the heartwood. Based on the fact that wood properties are a good indicator of changes that occur during trees' aging and under the influence of external factors, they can be used to make parallel comparisons.

Aim of the paper was to compare radial variation of basic density, compressive strength along the grain, and static bending strength of the Scots pine grown on varied conditions determined by a soil type or by a way of soil exploitation before introducing current trees.

2. Research methods

The analyses were conducted in eight mature monoculture pine stands, V and VI age class, grown in optimal habitat conditions for the species. Two fields were chosen from each forest division: Drawsko-Pomorskie Forest Division, Trzebielino Forest Division, Warcino Forest Division (RDSF Szczecinek), and Olesno Forest Division (RDSF Katowice). On the basis of the stand description, four stands were classified as growing on forest soil (L) and four as growing on former agricultural soil (P) (Table 1). Afforestation on former agricultural soil is defined as forest stands grown on the area in the first generation, as well as in the second if the first generation did not reach maturity because of tree fungal diseases (Forest Management Instruction 2012). Selection of stands from each location was done based on two criteria: a forest site type and stand quality index. We assumed that these would be identical features both for forest stand grown on former agricultural soil, and for forest stand grown on forest soil.

In each forest stand, on the 0,5 ha test field, diameter at breast height of all growing trees was measured and classified in 2-centimeter levels of thickness. Tree height was also measured in the group of trees selected in proportion to the number of trees within the same level of thickness. Measurements of model trees were done using the Urich I method. Three trees represented each stand (a total of 24 trees were selected). Average

Table 1. Selected taxation characteristics of stands with established mean sample plots

Location	Forest habitat	Age	Degree of crop density	d.b.h. [cm]	h [m]	Stand quality class	Stand density	Soil quality	Soil type
Drawsko Pom.	BMśw	88	0,9	30	22	II	Prz	L	RDb
	BMśw	88	0,8	32	23	II	Prz	P	RDb
Trzebielino	BMśw	100	0,9	32	22	II	Prz	L	RDb
	BMśw	86	0,9	33	23	II	Prz	P	RDb
Warcino	Bśw	97	0,9	30	22	II	Um	L	RDb
	Bśw	102	0,9	35	23	II	Um	P	RDb
Olesno	LMśw	101	1,0	34	27	I	Prz	L	RDw
	LMśw	91	1,0	33	28	I	Prz	P	RDw

L – forest soil; P – former farm land soil; Bśw – fresh coniferous forest; BMśw – mixed fresh coniferous forest; LMśw – mixed fresh broadleaved forest; RDb – rusty podzolic soil; RDw – rusty soil; Prz – dashed; Um – moderate height of model trees in the stand described as grown on former agricultural soil was 24,7±2,6 m, and diameter at breast height was 34,3±8,5 cm. The tree crown was characterised by average diameter of 5,6±1,4 m and average length of 7,4±1,5 m. Measurements of trees in stands described as grown on forest soil were: height 25,3±6,5 m, diameter at breast height 34,2±6,5 cm, diameter of tree crown 5,8±1,4 m, length of tree crown 7,2±1,4 m.

Samples from the level of diameter of breast height were collected for laboratory analyses towards further research. Average cambial age ($d_{1,3}$) of trees L was 93 years, and 90 years for trees P. Average breadth of the one-year-old ring in the group L was 1,5 mm, and that in the group P was 1,7 mm. Average contribution of late wood in the one-year-old ring was 36% in both analysed groups.

Normalised sampling was done from the collected material. Subsequently, according to standard specifications, basic density (Q_u), compressive strength along the grain (*CS*), and static bending strength (*BS*) were specified (PN-77/D-04101; PN-77/D-04103; PN-79/D-04102). Each section was represented by samples selected along four axes oriented according to four geographical directions. For each sample, relative distance of its location from the pith was measured. It was assigned to one of the five zones located along radius: I (0,00–0,20), II (0,21–0,40), III (0,41–0,60), IV (0,61–0,80), V (0,81–0,10). Therefore, data set was obtained and analysed using Statistica program. Normality of the distribution was tested using the Shapiro-Wilk test. Using the U Mann-Whitney test, values describing population were tested if they were equally high.

3. Research results

In total, basic density of pines grown on former agricultural soil (Q_{uP}) was 435 kg/m^3. It was significantly lower than the basic density of pines grown on forest soil (Q_{uL}), which was 478 kg/m^3. Values for each zone, containing selected fragments of diameter at breast height section, indicate that regarding basic density it was pith wood (zone I) that differed the most. The difference was 73 kg/m^3 (21,0%). Wood in the zone IV was the least differential. The difference was 21 kg/m^3 (4,6%). In the remaining zones, the following disproportions were observed: II 72 kg/m^3 (17,6%), III 34 kg/m^3 (7,3%), V 32 kg/m^3 (7,1%.) In all zones Q_{uL} was statistically significantly higher than Q_{uP} (Table 2).

Radial variation Q_u was very similar in the pith part (zone I and II). Maximum of the parameter value increase was in zone III (Q_{uL} earlier was closer to the pith). Then, significant decrease could be observed. However, Q_{uP} decreased in proportion to the increase of the distance from the pith, and Q_{uL} started to increase again at some point. Between zones I and II, Q_{uP} increased by 64 kg/m^3 on average, and between zones II and III by 47 kg/m^3. However, between zones III and IV it decreased by 4 kg/m^3, and between IV and V by another 4 kg/m^3. Regarding Q_{uL}, differences were in the following order: 63,9, 17,7 kg/m^3 (Table 2).

Multiple testing of Q_u proved that in trees P and L the pith zone of cross-section (I) differed statistically from the remaining zones. As distinct from tree L, in tree P statistical differences were also observed between zones II and III, III and IV, and IV and V (Table 3). Analysing differences strictly between neighbouring zones, it was observed that in P statistical significant disproportion was

Table 2. Characteristics of the basic density (Q_u) and U Mann-Whitney test results

Zone	Growth conditions – farmland soil				Growth conditions – forest soil				*p*
	Q_u [kg/m^3]	*n*	*SD* [kg/m^3]	*VC* [%]	Q_u [kg/m^3]	*n*	*SD* [kg/m^3]	*VC* [%]	
I	348	26	45	12,9	421	27	55	13,1	**0,000017***
II	412	63	48	11,6	484	59	57	11,7	**0,000000***
III	459	68	45	9,8	493	64	35	7,2	**0,000007***
IV	455	68	45	10,0	476	60	35	7,4	**0,001048***
V	451	44	39	8,7	483	43	31	6,3	**0,000120***
Total	435	269	56	12,9	478	253	47	9,9	**0,000000***

n – sample size
SD – standard deviation
VC – variation coefficient
* marked effects are significant at $p<0{,}01$

Table 3. *P* values for multiple comparisons of basic density

Growth conditions – farmland soil						Growth conditions – forest soil					
Zone	I	II	III	IV	V	Zone	I	II	III	IV	V
I	–					I	–				
II	**0,0004**	–				II	**0,0000**	–			
III	**0,0000**	**0,0000**	–			III	**0,0000**	1,0000	–		
IV	**0,0000**	**0,0000**	1,0000	–		IV	**0,0000**	1,0000	0,2685	–	
V	**0,0000**	1,0000	**0,0000**	**0,0001**	–	V	**0,0000**	**0,0401**	**0,0000**	0,2229	–

Table 4. Characteristics of the compressive strength along fibre (*CS*) and U Mann-Whitney test results

Zone	Growth conditions – farmland soil				Growth conditions – forest soil				*p*
	CS [MPa]	*n*	*SD* [MPa]	*VC* [%]	*CS* [MPa]	*n*	*SD* [MPa]	*VC* [%]	
I	14,91	22	4,12	27,67	19,71	26	4,59	23,31	**0,000436***
II	18,70	63	4,67	24,98	22,61	59	4,52	19,97	**0,000009***
III	21,07	64	3,82	18,11	22,78	62	3,97	17,42	**0,010148****
IV	20,86	66	4,48	21,49	21,77	60	3,65	16,78	0,131432
V	19,97	41	4,17	20,88	20,88	42	3,30	15,79	0,153494
Total	19,73	256	4,61	23,35	21,85	249	4,09	18,72	**0,000000***

* marked effects are significant at $p<0,01$
** marked effects are significant at $p<0,05$
other designations as in Table 2

Table 5. *P* values for multiple comparisons of the compressive strength along fibre

Growth conditions – farmland soil						Growth conditions – forest soil					
Zone	I	II	III	IV	V	Zone	I	II	III	IV	V
I	–					I	–				
II	**0,0000**	–				II	**0,0000**	–			
III	**0,0000**	0,2323	–			III	**0,0000**	1,0000	–		
IV	**0,0000**	0,5727	1,0000	–		IV	**0,0000**	1,0000	1,0000	–	
V	**0,0000**	1,0000	**0,0000**	**0,0000**	–	V	**0,0007**	**0,0000**	**0,0000**	**0,0030**	–

Table 6. Characteristics of the static bending strength (*BS*) and U Mann-Whitney test results

Zone	Growth conditions – farmland soil				Growth conditions – forest soil				*p*
	BS [MPa]	*n*	*SD* [MPa]	*VC* [%]	*BS* [MPa]	*n*	*SD* [MPa]	*VC* [%]	
I	31,75	22	10,30	32,45	42,67	24	15,53	36,38	**0,010747****
II	45,55	56	13,56	29,76	55,57	57	11,78	21,20	**0,000011***
III	54,04	60	14,47	26,77	59,18	63	12,43	21,00	**0,015799****
IV	51,55	65	11,35	22,01	55,95	52	11,46	20,48	0,108554
V	51,25	37	8,32	16,24	56,52	38	12,77	22,59	0,081735
Total	48,91	240	13,69	27,98	55,46	234	13,18	23,77	**0,000000***

* Marked effects are significant at $p<0,01$
** Marked effects are significant at $p<0,05$
other designations as in Table 2

Table 7. *P* values for multiple comparisons of static bending strength

Growth conditions – farmland soil						Growth conditions – forest soil					
Zone	I	II	III	IV	V	Zone	I	II	III	IV	V
I	–					I	–				
II	**0,0000**	–				II	**0,0000**	–			
III	**0,0000**	**0,0069**	–			III	**0,0000**	0,7864	–		
IV	**0,0000**	**0,0173**	1,0000	–		IV	**0,0000**	1,0000	**0,0010**	–	
V	**0,0000**	1,0000	**0,0000**	**0,0000**	–	V	**0,0000**	**0,0015**	**0,0000**	0,9125	–

between zones I and II, II and III, IV and V; otherwise, it was only between zones I and II in L (Table 3).

Compressive strength along fibres of Scots pines grown on former agricultural soil (CS_P) was statistically significantly lower than wood of pines grown on forest soil (CS_L). Analysing differences in each zone, the highest differences were observed in zones I and II in the following order: 4,80 and 3,91 (MPa), i.e. 32,2% and 20,9%, respectively, statistical significant at $p<0{,}01$. In zone III, the difference was 1,71 MPa (8,1%) and it was statistical significant at $p<0{,}05$. In zones IV and V, observed disproportions numbered 0,91 MPa, viz. about 4% and they were not statistical significant (Table 4).

Radial variation CS_P and CS_L was comparable, however CS_P changes seemed to be more dynamic (zones I, II). In both analysed cases, the maximum of the parameter value increase was located at the mid-length of the radius (the zone III). When it crossed the maximum, the average value of *CS* decreased, although changes in CS_L values were of greater dynamics. Average value CS_P of zone II was higher than the value of zone I by 3,8 MPa, and of zone III by 2,4 MPa than of zone II. The value of zone IV compared to that of zone III was lower by 0,2 MPa, and of zone V compared to zone IV by 0,9 MPa. The CS_L differences between zones were in the following order (from the pith to circumference direction): 2,9; 0,2; 1,0; 0,9 MPa (Table 4).

Multiple testing of average *CS* for each zone indicated that there were similar diversity of values in L and P. Absence of differences between zones II and V in P was an exception. When neighbouring zones were compared, statistical significant differences in P and L were found only between zones I and II, besides IV and V (Table 5).

Similar to case Q_u and *CS*, wood of trees grown on forest soil (BS_L) was of higher static bending strength. The observed difference was 6,55 MPa (13,4%) and it was statistical significant. Regarding *BS*, wood of zone I (10,9 MPa) differed the most, and wood of zone IV (4,4 MPa) the least. In zone II, differences were statistical significant at the level $p<0{,}01$, but in zones I and III at $p<0{,}05$. In zones IV and V, statistical differences were not observed (Table 6).

The analysed groups of trees were characterised by similar value distribution of static bending strength (*BS*) on the radius. In the pith zone the value of *BS* increased dynamically. Differences between zones I and II were 13,8 MPa for the group of trees grown on former agricultural soil, and 12,9 MPa for the group of trees grown on forest soil. Differences between zones II and III were slightly lower and were in the following order: 8,5 and 3,6 MPa. In the zone III, viz. at the mid-length of the radius, the value of *BS* reached maximum and when compared, in zone IV it was significantly lower by 2,5 MPa (former agricultural soil) and 3,2 MPa (forest soil). Between zones close to the circumference (IV and V), the observed differences were small: about 0,3 for trees grown on former agricultural soil and 0,6 MPa for trees grown on forest soil (Table 6).

Parameter diversity *BS* was similar to Q_u. The pith zone (I) differed the most from other zones. It was observed both in case of trees grown on former agricultural soil and trees grown on forest soil. Remaining statistical significant differences are presented in Table 7.

4. Discussion

Genes and tree growth and development conditions influence cambium activity and – ipso facto – wood structure. Hence, wood properties are affected by a combination genetic and environmental factors, i.e. reflection of changes in tree and its environment.

The paper presents results of radial variation in selected technical wood parameters of Scots pines. We assumed that growth and development conditions, specified by soil type or the way of using it before introducing the current tree generation, are the differentiation factor.

Average values for basic density of analysed wood, viz. 435 kg/m^3 for trees grown on former agricultural soil and 478 kg/m^3 for trees grown on forest soil, are similar to wood density of the species in this geographical location (Paschalis 1980; Witkowska 1997). Likewise values of compressive strength along fibres (P – 19,73 MPa, L – 21,85 MPa) and static bending strength (P – 48,91 MPa, L – 55,46 MPa) are similar, for instance, to values in the Pazdrowski (1992) and Pazdrowski (2004) research.

Jelonek et al. (2005, 2010) claim that wood density of trees grown on former agricultural soil is higher, and that the static bending strength and compressive strength along fibres are lower (by wood humidity over fibre saturation point) than wood density and wood mechanical properties of trees grown on forest soil. In our opinion, tree tissue properties at the level of cell-wall are the reason of the aforementioned phenomenon. Results obtained from our research are analogous to mechanical parameters. However, the result obtained in regard to basic density is opposite. Scots pine grown on former agricultural soil increases its thickness more dynamically than on the forest soil, in the juvenile age particularly (Tomczak et al. 2009). Hence, it influences wood properties, because in regard to conifers it negatively correlates with the amount of annual growth increment thickness (Lindström 1996; Aleinikovas 2007). Hence, the pith zone is significant for comparison in the trunk cross-section. In the pith zone, differences between basic density and wood strength of P and L were statistically significant. In the zone close to circumference, wood differs only on the basis of basic density.

Wood located in the central part of a trunk cross section is a distinctive type of tree tissue. Regarding structure and properties, juvenile wood, that is distinctive in regard to macro- and microscopic properties, differs from mature wood that surrounds it (Tomczak et al. 2010; Gryc et al. 2011, Tomczak, Jelonek 2012). Such distinctness is a feature natural for every species, and is observed regardless of the factor that differentiates a group of researched trees (Abdel-Gadir, Krahmer 1993; Guler et al. 2007). Basic density and wood strength of Scots pine increase from the pith to circumference direction. It increases very dynamically at the beginning, what is a commonly known as regularity (Kärenlampi, Riekkinen 2004). On the basis of the obtained results, it was observed that only zone I (located closest to the pith) differs statistically from all the remaining zones with regard to both basic density and static bending strength, including compressive strength along the fibres. The zone that differed significantly from other zones was also a part of trunk's cross section and was located on the circumference. It was observed that the basic density and wood strength first increase and then decrease. However, regarding wood density and strength of trees grown on forest soil in the zone close to the circumference, a re-increase of values was observed.

According to Klisz (2011), wood structure (biometrical properties of tracheid) remains influenced strongly by genetic factors, whereas growth rings' properties are influenced by the dominating environmental factors (average temperature in selected months of the growing season). Comparing radial variation in analysed technical wood parameters, it can be assumed that it is influenced by genetic factors mostly. However, the obtained values of analysed properties indicate that it is rather an influence of environmental factor (soil type).

The factor included in the research (soil type) differentiates groups of trees based on the values of analysed wood properties mostly. Radial variation of basic density and static bending strength, as well as compressive strength along the fibres of Scots pines grown on former agricultural soil and forest soil is very similar. However, changes are more dynamic with regard to pines grown on former agricultural soil. Hence, such wood is more heterogeneous.

5. Conclusions

1) Radial variation in wood properties of Scots pine grown on former agricultural soil is similar to variability that is characteristic for the control trees grown on forest soil.

2) In both groups of trees, the lowest basic density and strength were observed in the pith (juvenile) zone. Wood of highest basic density and strength was located in the central part of radius.

3) Wood from the cross-section part close to the circumference in both groups of trunk differs significantly only in regard to basic density.

4) Wood of Scots pine grown on former agricultural soil compared to wood of trees grown on forest soil is characterised by significantly lower basic density, static bending strength, and compressive strength along fibres.

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