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The estimation of biomechanical stability parameters of trees growing under former farmland conditions

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Abstract: *The estimation of biomechanical stability parameters of trees growing under former farmland conditions.* The paper presents an attempt at the determination of the effect of former farmland soils on biomechanical stability of trees through an analysis of axial variation in modulus of elasticity and static bending strength in wood with moisture content above fiber saturation point. Analyses were conducted on wood of Scots pines grown on four locations in southern Poland, coming from mature stands growing on soils of former farmland and on forest soils. Collected results indicate significant differences in analysed properties of wood between compared groups of trees. Different biomechanical stability was found in trees depending on their growth and development conditions.

Keywords: Scots pine, Biomechanical stability of trees, modulus of elasticity, Former farm land,

INTRODUCTION

Generally the stability of a body is defined as its ability to generate forces, which would restore the original state of equilibrium after it has been disturbed. Stability of trees is connected with their development and may be interpreted as the probability of their damage (Lundström 2010).

Mechanical stability of trees and stands was previously evaluated on the basis of statistical data describing probability of damage caused by wind at its average velocity. This approach to a limited degree contributes to our understanding of physical phenomena in the response of trees to the action of external forces. Studies conducted by Lohou et al. (2003) and Sellier et al. (2008) shed some more light on the mechanical stability of trees. These studies showed that stability of trees to a considerable degree depends on the species and local growth conditions and that trees are biomechanically complex structures, which are capable of adapting their cambium growth to external mechanical stresses.

Performed studies on the stability of trees and stands clearly show that their stability to a considerable degree is determined by the level of external load and by stand structure, which is composed of such traits as species composition, tree height and breast height diameter, area of the crown, depth and width of the root system, stocking and the type of soil (Coutts 1986; Kerzenmacher and Gardiner 1998; Peltola et al. 2000; Hale et al. 2004; Scott and Mitchell 2005; Peltola 2006).

Mechanical stability of Scots pine was described by Peltola et al. (2000). They investigated mechanical strength of standing trees aged from 40 to100 years. On the basis of conducted analyses they stated that trees with a greater breast height diameter at the same height will break at greater loads than trees with a smaller DBH. Moreover, trees with a higher slenderness factor break faster, while less slender trees are uprooted faster.

It was attempted in this study to determine biomechanical stability of mature pine stands grown on soils of former farmland.

METHODS

Analyses were conducted in mature pine stands of age class V, growing under conditions optimal for this forest-forming species at this latitude on former farmland and forest soils in the Olesno Forest Forest Division.

In each of the two study areas a 1-ha mean sample plot was established, in which breast height diameters were measured for all trees, while height was measured in proportion to the number of trees in the adopted (2 cm) diameter subclasses. On the basis of recorded diameter and height characteristics of trees 12 mean sample trees were selected (three for each plot) representing the first three classes in terms of the classification according to Kraft (1884) (tab. 1).

Table 1 Characteristics of trees

Growth conditions	Kraft class	Age [years]	DBH [cm]	Height [m]	Stand quality
Forest	I	93	41,0	28,8	I
	II		33,0	28,0	
	III		28,5	27,5	
Former farmland:	I	90	38,5	29,5	
	II		29,5	28,0	
	III		27,0	25,7	

Model trees were felled and firstly selected biometric traits of trees were measured, i.e. tree length and the length of live crown.

On the basis of recorded biometric parameters of trees their slenderness factor was calculated, being a ratio of their height to breast height diameter (Jaworski 2004).

Next from felled trees material was collected for analyses of selected mechanical properties of wood, i.e. static bending strength (Rg) oraz modulus of elasticity (Em). Material for laboratory analyses came from 50-cm blocks collected from a distance of 1,30 m – 1,80 m the kerf plane (A), next from the mid-length of the stem (B) and the base of live crown (C).

Static bending strength and modulus of elasticity were tested on samples which moisture content exceeded fiber saturation point.

Mechanical properties of wood were tested in accordance with the respective standards (PN-79/D-04102 and PN-63/D-04117).

Collected empirical material was analysed using mathematical statistics methods with the use of the Statistica 9.0 PL statistical software package.

RESULTS

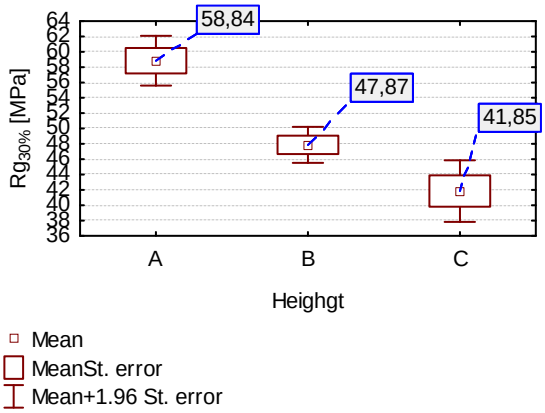
It was attempted in this study to analyse stability of stands growing on soils of former farmland and forest soils on the basis of axial variation of static bending strength of wood with moisture content above fiber saturation point and modulus of elasticity at static bending. In case of static bending strength, statistically significantly higher values were recorded in case of wood from pines coming from forest soils, amounting on average to 54,81 [MPa], while in wood coming from trees growing on former farmland this strength was on average 51,76 [MPa]. Significant differences were found in axial variation of the analysed property. Both in case of strength of wood from pines coming from forest soils and from former farmland soils static bending strength decreases as we consider higher sections of the stem. The highest values were recorded at breast height, while the lowest at the base of live crown (tab 2., Fig. 1)

Table 1 Statistical characteristics of static bending strength and modulus of elasticity in wood of Scots pines growing on soils from former farmland and forest soils

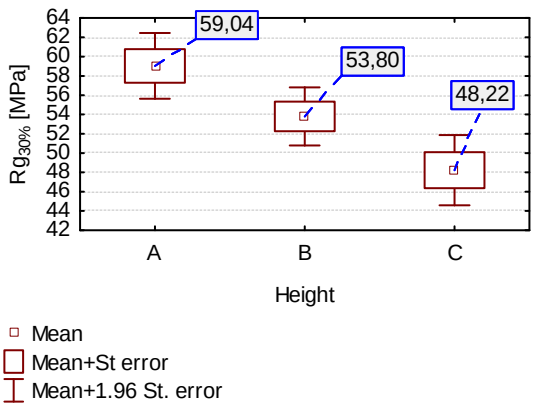
	Growth conditions	Height	Mean [MPa]	Minimum [MPa]	Maximum [MPa]	Standard deviation [MPa]	Coefficient of variation [%]
$Rg_{w30\%}$	Former farmland *	A	58.84 *	16.17	81.58	12.17	20.68
		B	47.87 *	22.23	63.71	22.23	46.44
		C	41.85 *	3.59	55.96	3.59	8.58
	Forest *	A	59.04 *	0.54	88.95	13.7	23.2
		B	53.8 *	34.7	101.9	11.58	21.52
		C	48.22 *	33.61	83.3	10.34	21.44
$Em_{w30\%}$	Former farmland *	A	5326 *	3067	7968	1438	27.0
		B	6032 *	1721	8468	1402	23.24
		C	5361	2482	7549	1337	24.93
	Forest *	A	6308 *	2990	9172	1189	18.85
		B	5382 *	2564	7910	1215	22.57
		C	5084 *	2781	6759	922	18.14

* differences significant statistically at the level of significance $p \leq 0.05$

Moreover, it was found that wood of pines growing on forest soils was characterised on average by higher strength at each of the investigated levels than wood of pines growing on former farmland soils (Figs. 1a and 1b).



Axial variation of static bending strength of wet samples ($W_{30\%}$) of wood from Scots pine (*Pinus sylvestris* L.) grown on former farmland soils



Axial variation of static bending strength of wet samples ($W_{30\%}$) of wood from Scots pine (*Pinus sylvestris* L.) grown on forest soils

Similarly as in case of static bending strength, modulus of elasticity (Em) was significantly higher in case of pines grown on forest soils, amounting on average to 5703 [MPa], while in wood of pines coming from former farmland soils it was 5411 [MPa]. Only in case of pines grown on forest soils modulus of elasticity decreased with the increasing height of the stem and it was statistically significantly highest at breast height (A=6309 [MPa]). Despite the fact that at mid-height of cleared stem (B) the value of this modulus was lower than at the height of the base of live crown (B), no statistically significant differences were found between these two levels (tab. 2, Fig. 2b).

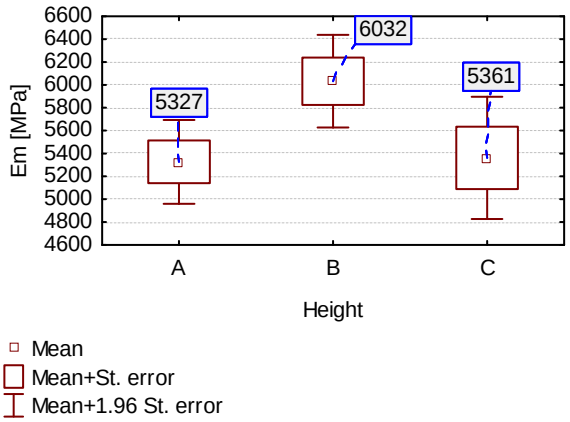


Fig. 2a Axial variation of modulus of elasticity in wood of Scots pine (*Pinus sylvestris* L.) grown on former farmland soils

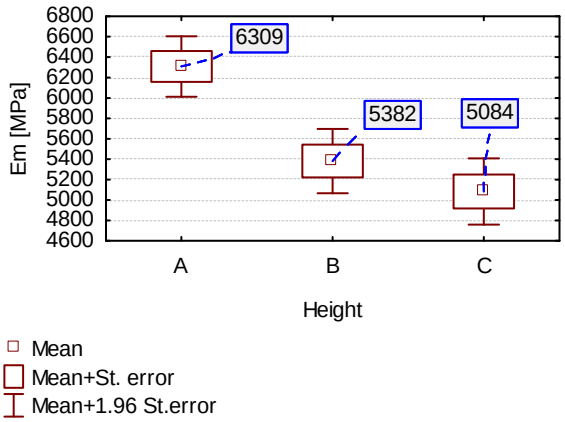


Fig. 2b Axial variation of modulus of elasticity in wood of Scots pine (*Pinus sylvestris* L.) grown on forest soils

Modulus of elasticity in wood of pines grown on former farmland soils differed from that of wood from pines coming from forest soils. The highest values of modulus of elasticity were found at mid-length of cleared stems (B=6032 [MPa]), while at breast height (A) and the base of live crown (C) its values were similar (tab. 2, Fig. 2a).

DISCUSSION AN CONCLUDIONS

Studies on biomechanical models of trees focus typically on rigidity of the stem, resistance to breaking and on elastic stability (Baker 1995; Heli and Peltola 2006; Peltola 2006). It was attempted in this study to determine biomechanical stability of Scots pine grown on former farmland soils in comparison to trees growing under soil conditions typical of forests.

The gradual decrease in the properties analysed in this study, which is observed with an increase in height, seems to be justified. This is confirmed by the frequently stressed (Niclass 1992; Coutts and Grace 1995; Mencuccini et al. 1997) multifunctional role of the stem, which while raising the crown upwards has to provide it with an adequate mechanical support. At the same time it has to serve a hydraulic function, thus being subjected to optimization of its structure in terms of served functions.

An atypical fluctuation was observed in radial variation of modulus of elasticity in trees grown on former farmland soils, which due to the ratio of crown length to tree height may most probably be ascribed to the centre of gravity being located high on trees.

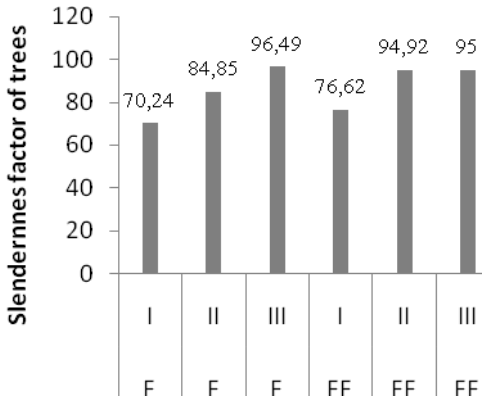


Fig.3 Slenderness factor of trees – stability of trees

For the purpose of a more comprehensive analysis of stability in trees from the compared groups their slenderness factor was determined. It is considered an appropriate measure for the determination of stability of trees and their resistance to wind (Jaworski 2004; Peltola 2006).

The discussed coefficient in case of trees growing on forest soils was 84 and it was similar to the coefficient recorded for pines growing on former farmland soils (89), which makes them similar in terms of such specified stability (Fig. 3). Conducted analyses indicate

that there are differences in mechanical properties, which are determined by changes occurring at the structural level in the wood tissue, which results in a situation when the analysed and commonly applied slenderness factor of trees is only partially of an application character, since it does not take into consideration changes in the biomechanical system of trees. On the basis of conducted investigations we may infer a lower biomechanical stability of stands growing on soils of former farmland.

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Streszczenie: *Ocena biomechanicznych wskaźników stabilności drzew rosnących w warunkach gruntów porolnych.* W pracy podjęto próbę określenia wpływu gruntów porolnych na biomechaniczną stabilność drzew poprzez analizę osiowej zmienności modułu sprężystości oraz wytrzymałości na zginanie statyczne drewna o wilgotności powyżej punktu nasycenia włókien.
Do badań użyto drewno sosny zwyczajnej wyrosłej na czterech stanowiskach w południowej Polsce pochodzącej z drzewostanów rębnych wzrastających w warunkach gruntów porolnych oraz leśnych. Uzyskane wyniki wskazują na występowanie istotnych różnic analizowanych w pracy właściwości drewna pomiędzy porównywanymi grupami drzew. Stwierdzono odmienną stabilność biomechaniczną drzew w zależności od warunków wzrostu i rozwoju.

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