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PROPORTION OF SAPWOOD AND HEARTWOOD AND SELECTED BIOMETRIC FEATURES IN LARCH TREES (*LARIX DECIDUA MILL.*)

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ABSTRACT

In the study, an attempt was made to determine the formation of the volume and the proportion of sapwood and heartwood in the tree stems of the European larch. In addition, the authors tried to ascertain whether a correlation can be found between the volume and the proportion of both types of wood and the breast height diameter, tree height and selected (quantitative) biometric features of tree crowns. The performed experiments comprised stands with considerable proportion of the European larch of the I, II, III and IV class of age which developed in conditions of the fresh mixed broad-leaved forest.

A distinct correlation was found between the volume and proportion of sapwood and heartwood in the tree stems and the breast height diameter, tree height and selected biometric features of larch tree crowns. The influence was apparent in different ways and intensity as shown by the calculated determination coefficients (R2) and the plotted diagrams of the analysed features.

KEY WORDS: sapwood, heartwood, tree crown diameter, area of the crown projection, crown volume, crown area, European larch.

INTRODUCTION

Heartwood makes up the internal part of the tree trunk or stem which, in growing trees, is deprived of live cells. Instead of such nutrients as starch, heartwood compounds – tannins and primarily flavonoids – occur there (Zimmerman and Brown 1981, Hejnowicz 2002).

According to Ziegler (1968), Zimmermann and Brown (1981) heartwood is the result of ageing of the live wood tissue. The process of heartwood development is inseparably associated with the dying of the parenchyma cells. It can occur as a result of genetically programmed process of cell ageing which, however, depends on a number of external factors which provide epigenetic information (Hejnowicz 2002).

Bamber (1976) claims that the formation of heartwood is a regulatory process employed to maintain the sapwood surface on the optimal level. According to this author, the initiation of the process of heartwood formation is the result of the activation of a hitherto unknown signal inside the tree. Most trees possess regular heartwood across their cross sections with the shape similar to the circumference of the trunk. In some species, heartwood may have irregular shapes which do not correspond to the boundary of the annual ring (Hillis 1987)

According to Berthier et al. (2001) the proportion of heartwood in the tree trunk is irregular in the radial and longitudinal directions which may indicate that the heartwood formation is a developmental process regulated inside the tree itself.

European larch belongs to forest-forming species whose timber is divided into sapwood and heartwood (Krzysik 1978, Surmiński 1986, Kokociński 2002).

Both kinds of timber exhibit different technological characteristics which affect possibilities of the application or utilisation of the timber raw material. According to Leibundgut (1966), in trees which produce heartwood, including larch, a large proportion of coloured heartwood is advantageous.

Optimisation of silvicultural procedures and utilisation of the produced timber raw material requires its appropriate evaluation. This evaluation, apart from the type, dimensions and basic timber defects, should take into account, in the extent wider than it has done so far, macro- structure features of the produced timber as well as possibilities of its utilisation. Sapwood and heartwood are considered to be the main macro - structure features of timber significantly influencing its quality and value. From the cognitive as well as silvicultural and industrial points of view, it is important to determine possible interrelationships between some tree biometric features and the quality of their timber assessed on the basis of selected macro -structure features. Our better understanding of these interrelationships will allow, in a longer time perspective, such knowledge to be utilised in the process of production of high technical quality timber of predetermined purpose. The objective of this study was to ascertain the existence of possible relationships between the tree breast height diameter, its height, selected crown biometric features, on the one hand and, on the other, the volume of volumetric proportion of sapwood and heartwood in the stems of the European larch *(Larix decidua Mill.)* developed in conditions of the fresh mixed broad-leaved forest site type.

MATERIAL AND METHODS

Experiments were conducted in the Babimost Forest District which constitutes part of the Regional Directorate of State Forests (RDSF) in Zielona Góra (Fig. 1).

Larch occurred in the analysed stands in the form of group mixture. The trees developed in conditions of the fresh mixed broad-leaved forest site type and represented the I, II, III and IV age classes. On all eight experimental sample plots, i.e. two in each of the analysed age classes, breast height diameters of all trees as well as the height of growing trees proportionally to the adopted 2 cm frequencies of thickness degrees were measured. Having obtained the thickness-height characterisation of larch trees in this way, the Urich ll (Grochowski 1973) dendrometric method was then applied to determine dimensions of three sample trees representing the main stand, i.e. the three first classes according to Kraft's classification (the pre-dominant, dominant and co-dominant trees) (Kraft 1884). The dimensions of test trees were calculated individually for each of the analysed stands and each age class. The selected test larch trees were characterised by healthy and straight stems and symmetrical, properly developed crowns. The total of 24 test trees was selected. Before felling individual model trees, their crowns were projected in order to determine their diameters. The trees were then felled and next their lengths as well as the length of the live crown zones were measured. The measurements were carried out with the accuracy of 1 cm. On the basis of the obtained crown dimensional parameters of the felled trees, areas of the crown projection (using the formula for the area of the circle), volume of the crown cone as well as the total area of the crown cone were determined. All stems of the felled mean sample trees were divided into sections from the middle of which discs approximately 3 cm thick were cut out perpendicularly to the longitudinal axis of the tree trunk.

Fig. 1: Babimost Forest District which constitutes part of the Regional Directorate of State Forests (RDSF) in Zielona Góra (http://www.lasypanstwowe.gov.pl/mapy/index.htm)

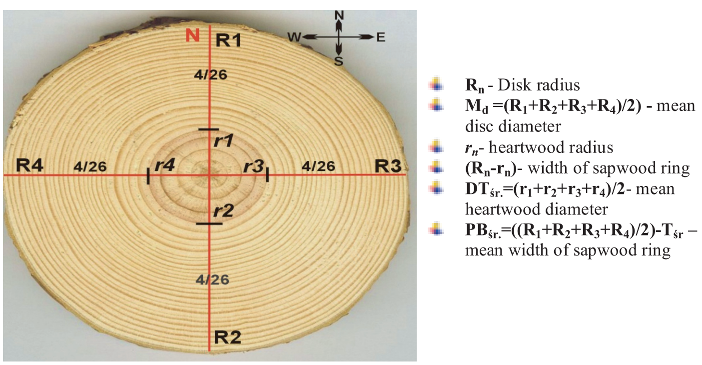

Fig. 2: Diagram of the measurement of the disc diameter, heartwood diameter and sapwood ring

The first disc was cut off the plane of the felled tree; the next ones, at the distance of 1 m from the above-mentioned plane and then from the middle of the adopted 2 m sections. The obtained discs, following their slight drying and good polishing, were used to measure the width of the sapwood ring as well as the diameter of the heartwood on two perpendicular diameters oriented along the north-south and east-west directions (Fig. 2).

On the basis of the obtained measurements, the authors calculated the volume of the sapwood ring and the volume of the heartwood cylinder in each of the 2 m sections of individual model trees which, ultimately, made it possible to calculate the total volume and proportion of both types of wood in each of the analysed mean sample trees.

The proportion of both types of wood in the stem volume were expressed in relative values (%) adopting the stem volume as 100% as well as with the assistance of B and T coefficients. The first of them (B) was expressed by the ratio of the sapwood volume to the heartwood volume, whereas the second one (T) was the outcome of the quotient of the heartwood volume to the sapwood volume. The obtained numerical values characterising the selected tree biometric characters as well as the selected traits of the macrostructure of their wood allowed the authors to carry out the analysis of interrelationships existing between them. An attempt was made to ascertain to what extent the individual biometric traits of trees precondition the magnitude and variability of the selected wood macrostructural traits. In this study, these relationships were characterised by means of determination coefficients and regression curves (Kala 2003, 2005).

RESULTS

The numerical data characterising the volume and proportion of the sapwood and heartwood in the stems of the European larch *(Larix decidua Mill)* are presented in Tab. 1.

The obtained statistical characteristics of the stem, sapwood and heartwood volume as well as B and T coefficients indicate their considerable variations within the analyzed tree population. A relatively high variability of the analyzed characters was found in larch trees representing the first age class. Particularly high values of variability coefficients were obtained with respect to the volumes of heartwood, sapwood and the entire stem. As the trees grew older, the calculated variability coefficients of the analysed traits decreased. The only exception was the variability of the B and T coefficients in larch trees derived from the III and IV age classes (Tab. 1).

The proportion of sapwood in the European larch trees (I age class) was high and amounted to 75%, while that of heartwood – to 25%. On the other hand, in the II, III and IV age classes, the proportion of heartwood exceeded significantly the proportion of sapwood in the tree stems and amounted to: 57%, 66% and 70%, respectively (Tab. 1).

The above-mentioned correlation is also corroborated by the calculated B and T coefficients.

Tab. 2 presents statistical characteristics of selected biometric features of the European larch model trees *(Larix decidua Mill.)* developed in conditions of fresh mixed broad-leaved forest.

The obtained numerical data indicate their variability within the analyzed age classes of the experimental trees. A relatively significant variability was found with regard to the crown volume, area of the crown projections and the total crown area. Values of the calculated variability coefficients ranged from 40.2% to 87.2%, from 32.7% to 62.3% and from 25.5% to58.1%, respectively (Tab. 2). The remaining tree biometric characteristics were characterised by considerably greater stability as confirmed by the calculated variability coefficients shown in Tab. 2.

Tab. 1: Statistical characterisation of the volume and proportion of sapwood and heartwood in stems of European larch (Larix decidua Mill.)

Age class	Measures of position and dispersion	Volume without bark [m^3]			Coefficient	
		stem	sapwood	heartwood	B	T
I	Mean	0.08	0.06	0.02	3.00	0.33
	[%]	100	75	25	100	100
	SD	0.05	0.04	0.02	1.09	0.16
	Var. coefficient	62.5	66.7	100.0	36.3	48.5
II	Mean	0.47	0.20	0.27	0.74	1.35
	[%]	100	43	57	25	409
	SD	0.24	0.10	0.14	0.19	0.24
	Var. coefficient	51.1	50.0	51.8	25.7	17.8
III	Mean	1.04	0.35	0.69	0.51	1.97
	[%]	100	34	66	17	597
	SD	0.38	0.11	0.29	0.24	0.82
	Var. coefficient	36.5	31.4	42.0	47.0	41.6
IV	Mean	1.07	0.32	0.75	0.43	2.34
	[%]	100	30	70	14	709
	SD	0.36	0.11	0.30	0.17	0.63
	Var. coefficient	33.6	34.4	40.0	39.5	26.9

Coefficient B – ratio of sapwood to heartwood volume
Coefficient T – ratio of heartwood to sapwood volume

Tab. 2: Statistical characteristics of selected biometrical features of the European larch (Larix decidua Mill.) trees

Age class	Measures of position and dispersion	Tree biometrical traits						
		d 1.3	h	lk	dk	pk	ok	pow.k
		[cm]	[m]	[m]	[m]	[m^2]	[m^3]	[m^2]
I	Mean	13.47	12.64	6.92	2.41	4.75	11.73	32.29
	SD	4.03	2.25	1.47	0.51	2.10	7.97	14.06
	Variability coefficient	29.9	17.8	21.2	21.2	44.2	67.9	43.5
II	Mean	24.18	23.77	9.35	3.90	12.19	38.22	70.94
	SD	5.90	1.48	1.78	0.61	3.99	15.38	18.08
	Variability coefficient	24.4	6.2	19.0	15.6	32.7	40.2	25.5
III	Mean	32.58	28.60	9.49	4.96	20.83	72.41	101.5
	SD	6.21	1.22	2.26	1.53	12.24	54.91	55.12
	Variability coefficient	19.1	4.3	31.2	30.8	58.8	75.8	54.3
IV	Mean	35.28	28.36	9.07	5.11	22.09	75.03	102.46
	SD	8.82	2.44	2.48	1.56	13.77	65.41	59.52
	Variability coefficient	25.0	8.6	27.3	30.5	62.3	87.2	58.1

$d_{1.3}$ – tree breast height diameter (diameter at the height of chest in bark),
h – tree height,
lk – crown length,
dk – crown width,
pk – area of the crown projection,
ok – volume of the crown cone,
pow.k – total area of the crown (cone)

Figures 3 to 16 provide a synthetic picture of the performed investigations characterizing the interrelationships of the European larch *(Larix decidua Mill.)* wood expressed by the volume and proportion of sapwood and heartwood in tree stems and some biometric tree features Values of the calculated determination coefficients and the correlation figures show that the strength of individual interrelations varied.

The breast height diameter of trees preconditioned in about 94% the volume of softwood and heartwood and the proportion of the two types of wood in the tree stem in 62.0% and 67.3%, respectively (Fig. 3 and 4). On the other hand, the height of trees affected the softwood and heartwood volumes in, respectively, 85.8% and 95.6%, while the proportions of softwood and heartwood in the tree stems – in 69.9% and 82.6% (Fig. 5 and 6).

The analyzed biometric features of the tree crowns, frequently referred to as 'quantitative crown features' (Lemke 1966, Lemke and Woźniak 1976, Pazdrowski 1994a, 1994b) exhibit strong correlations with the softwood and heartwood volumes as well as with the proportions of both wood types in the stems of larch trees (Fig. 7 to 16).

High values of determination coefficients characterising interrelationships between volumes of sapwood and heartwood in tree stems were determined analysing crown diameters (d_k), area of the crown projection (p_k), crown volume (o_k) and crown area ($pow._k$). On the other hand, lower values were found in the case when the proportions of the two types of wood were expressed in absolute values.

Generally speaking, all the examined interrelationships were of curvilinear nature.

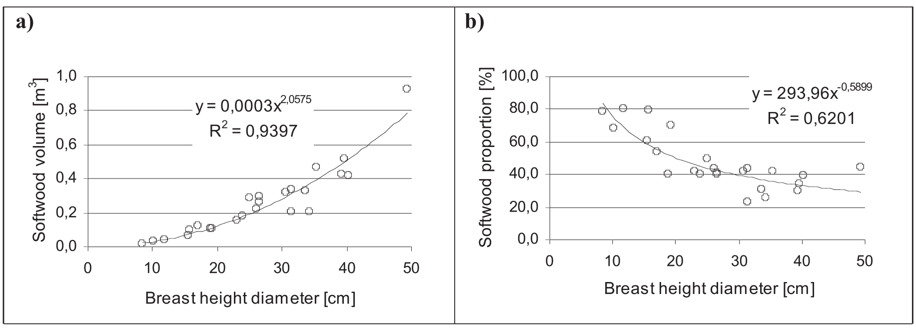

Fig. 3: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and breast height diameter of trees

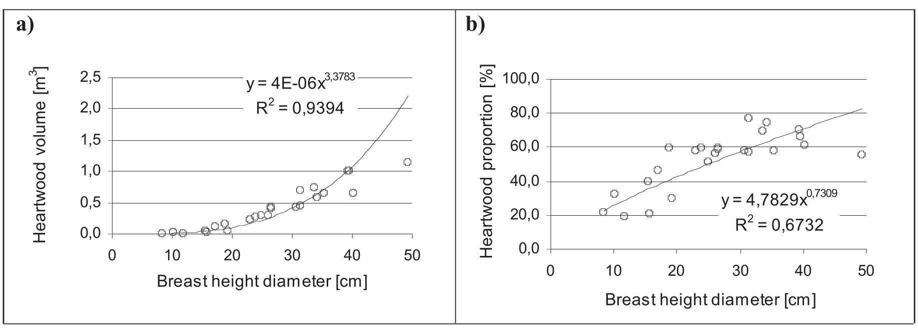

Fig. 4: Interrelation between the heartwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and breast height diameter of trees

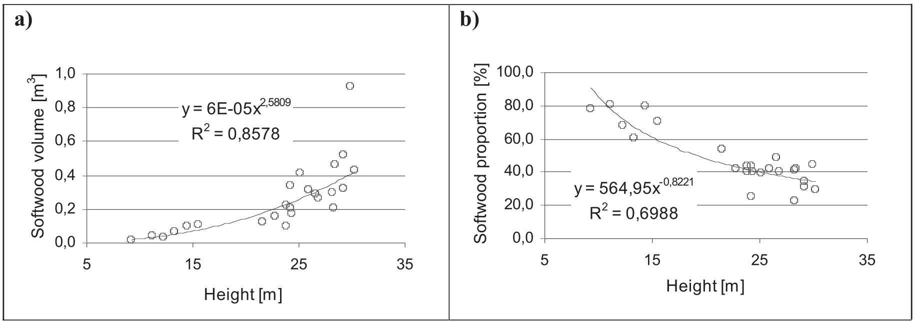

Fig. 5: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and height of trees

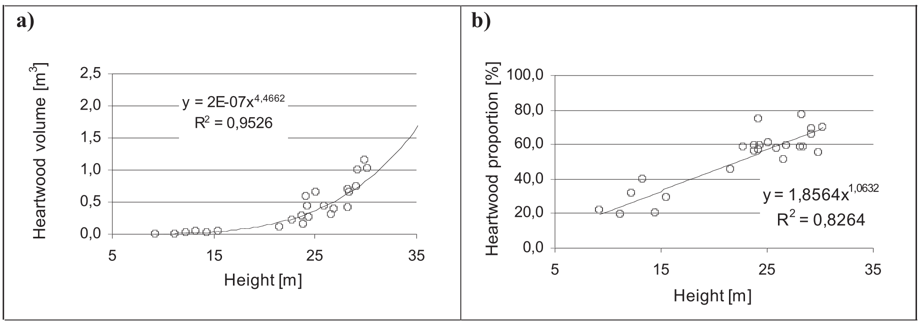

Figure 6: Interrelation between the heartwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and height of trees

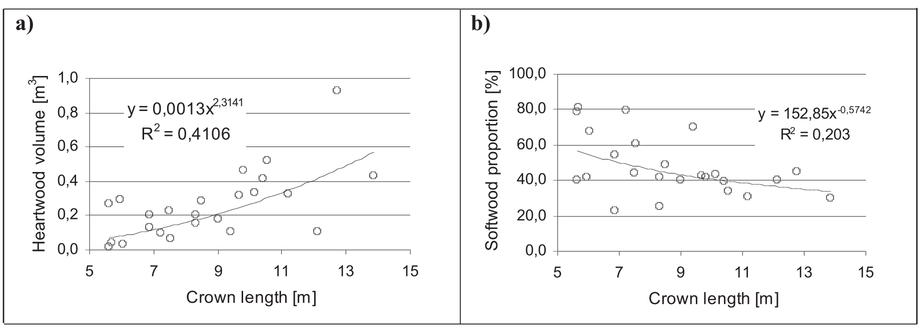

Fig. 7: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown length

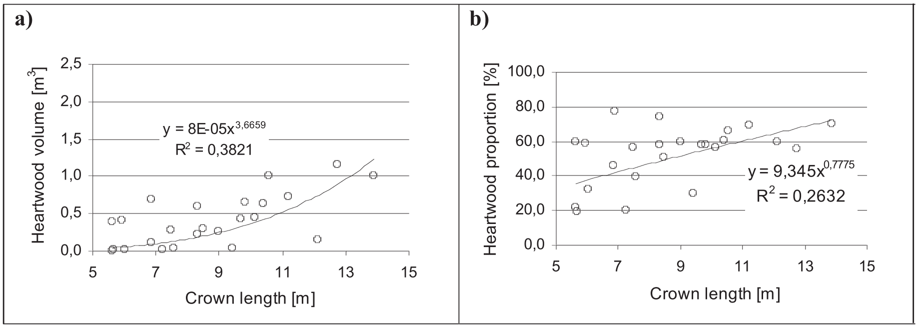

Fig. 8: Interrelation between the heartwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown length

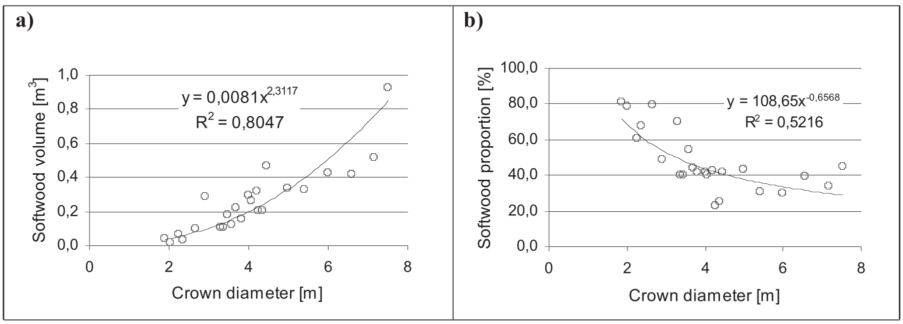

Fig. 9: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown diameter

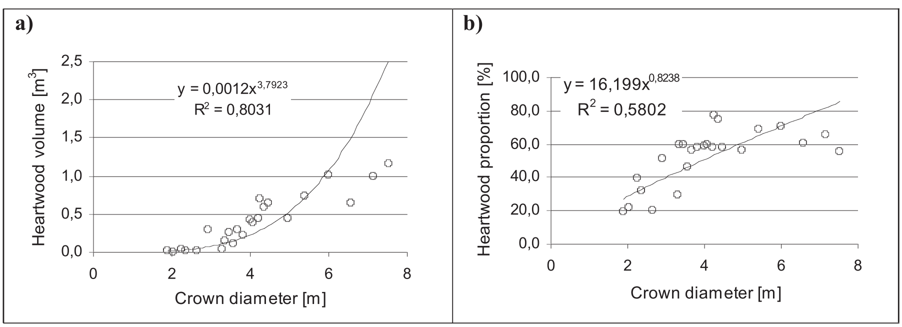

Fig. 10: Interrelation between the heartwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown diameter

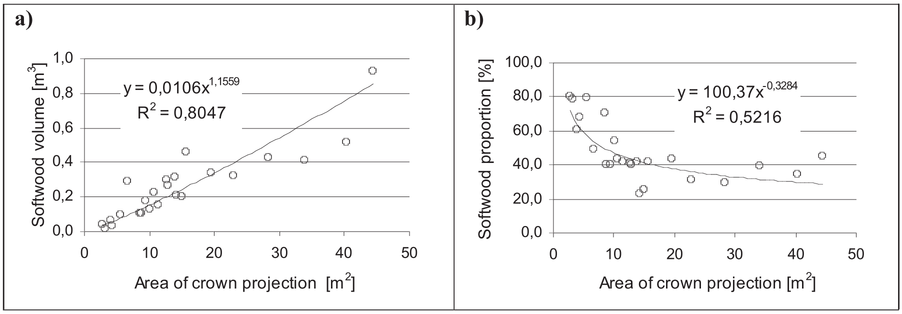

Fig. 11: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and area of crown projection

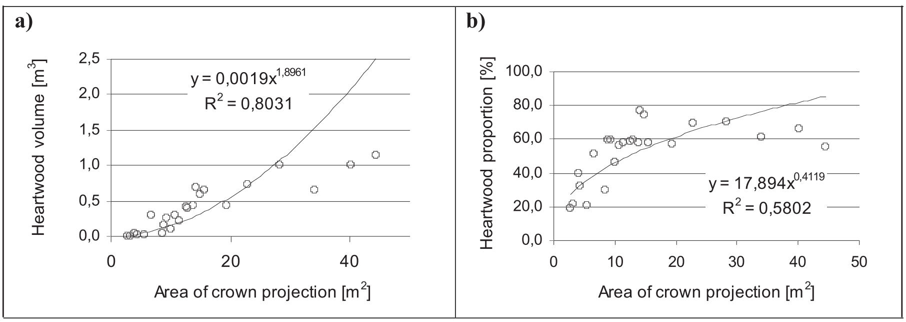

Fig. 12: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch on (Larix deciduas Mill.) area of crown projection

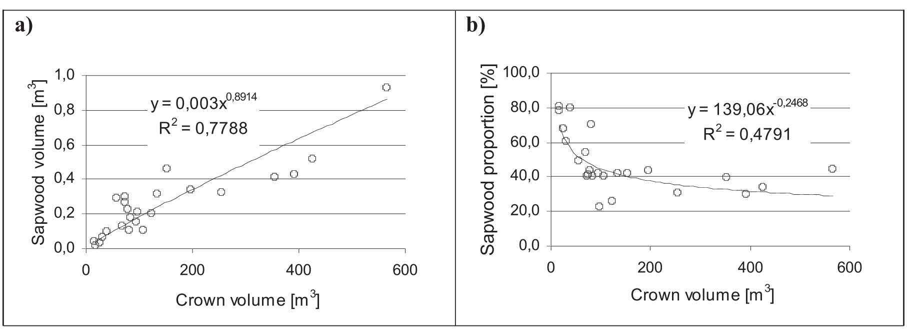

Fig. 13: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown volume

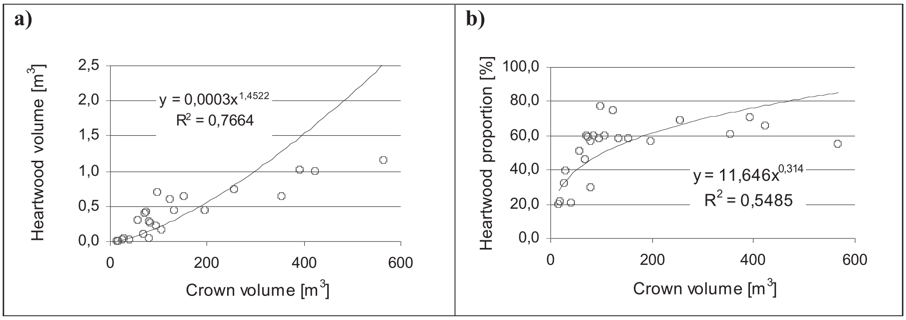

Fig. 14: Interrelation between the heartwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown volume

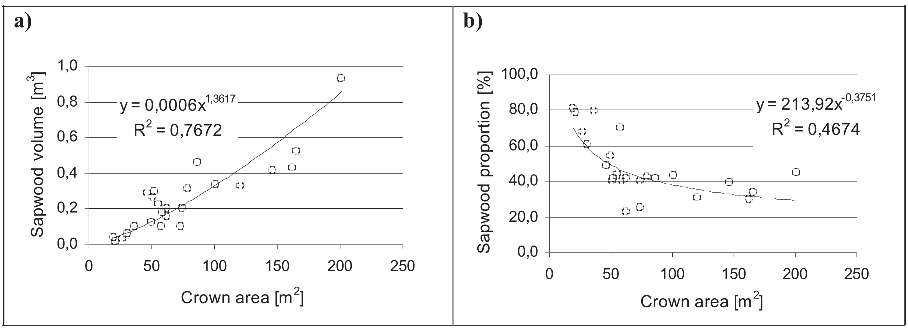

Fig. 15: Interrelation between the softwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown area

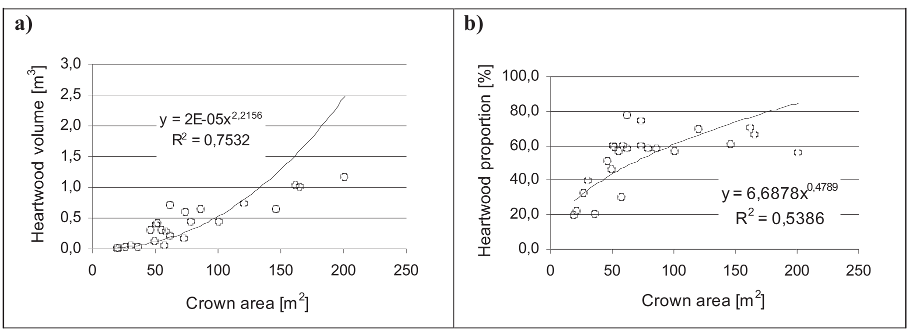

Fig. 16: Interrelation between the heartwood volume (a) and proportion (b) in the stems of European larch (Larix deciduas Mill.) and crown area

DISCUSSION

The observed growing deficit of timber, especially of good technical quality, and the increasing demand for this raw material makes it necessary to look for new ways which could improve the situation in this area. One of the possible options is to optimise the utilisation of the produced timber raw material, primarily, already in the standing stock. Optimal utilisation of wood for structural purposes as well as for other types of industrial applications requires its proper assessment. It is, therefore, essential to understand thoroughly mutual relationships between easy-to-assess tree biometric characters and sapwood and heartwood proportions in the stems of the European larch.

Substantial differences in the physical, chemical and mechanical properties of sapwood and heartwood are of considerable significance regarding possibilities of the application and utilisation of timber raw material.

Heartwood differs from sapwood in that its pits are closed (in coniferous species), it has a different content of water and gas, the oxygen content in the gas is identical as in the atmospheric air, it has a higher content of extractable substances and darker colour (Hejnowicz 1973, 2002). This wood zone does not participate in water conduction.

In physiologically healthy trees, there is balance between the conducting area in the tree stem (sapwood) and the transpiration area of the tree crown (Womperski and Iwanow 1984, Iwanow and Dubinin 1992). The transpiration-cohesion theory assumes a considerable stability of the system in which water columns move in the xylem as a result of the tension caused by transpiration (Kacperska 2002). Due to the development of extractive substances in the heartwood, the size of pores was significantly reduced in comparison with sapwood and that is why water absorption in heartwood is substantially smaller (Svensson and Nussbaum 1998).

The above process is aided, primarily, by the tree crown. In addition, the tree crown reflects the tree biotic potentials as well as its biosocial position in the stand (Assmann 1961, Czarnowski 1989). Wood volume increment in trees depends on the size of the assimilation apparatus and its assimilation energy (Lemke 1966, Lemke and Woźniak 1976).

One hypothesis (pipe model theory – PMT) claims that there is a significant correlation between the active cross section area (sapwood) and the crown foliage (weight, area of the assimilation apparatus) as confirmed by a highly significant regression between the plane of the sapwood surface and the crown area. This correlation was verified for different species, sites as well as different age classes (Shinozaki et al. 1964a, 1964b).

With the aim to assess the biomass of foliage and the sapwood xylem production, the above-mentioned theory was developed by numerous researchers, among others by Marchand 1983, Whitehead et al. 1984, Yukihiro 1997, Infante et al. 1999, Mäkelä and Vanninen 2001.

The obtained interrelationships between the volume and proportion of sapwood and heartwood in stems and biometric features characterising larch tree crowns find their justification in the pipe model theory (Shinozaki et al. 1964a, 1964b) which emphasises a strong relationship between the tree conductive part and its assimilation-transpiration apparatus. It is true that at so high determination coefficients (R^2), it can be presumed that, in the case of physiologically healthy trees, the crown to some extent, 'controls' the sapwood area in the tree to make sure it will secure the optimal "pipe" capable to provide appropriate quantities of water with mineral salts.

As to the remaining two tree biometric features analysed in this study, i.e. breast height diameter and tree heights, it has to be emphasised that they were very strongly connected with the occurrence of sapwood and heartwood in the examined tree stems as indicated by the calculated high determination coefficients. This can be attributed to the fact that the size of the tree diameter at the height of 1.30 m from the ground level (breast height diameter) and the tree height are correlated with each other and, at the same time, influence the biosocial position of a given tree in the community (stand). Trees characterised by bigger crowns and which are also taller are capable of more intensive transpiration which is quite likely to lead to more frequent water blockages which initiate the process of heartwood formation (Huber 1956, Zimmerman and Brown 1971).Essentially, the analyzed biometric characters, in the case of the European larch, all have considerable diagnostic value, since they allow us to determine the volume and proportion of both types of wood in tree stems.

CONCLUSIONS

1. The proportion of sapwood in larch trees representing the first age class was high and amounted to 75% of the tree stem, while that of the heartwood – to 25%. A reverse situation was observed in trees from the 2^{nd}, 3^{rd} and 4^{th} age classes as the proportion of heartwood exceeded significantly that of sapwood in tree stems and amounted to 57%, 66% and 70%, respectively.
2. The biometric features of European larch *(Larix decidua Mill.)* trees developed in conditions of the fresh mixed broad-leaved forest site type analyzed in the presented study affected the volume of sapwood and heartwood as well as the proportion of these woods in tree stems. This impact found its expression in different ways and varying intensity as confirmed by the calculated determination coefficients and the obtained diagrams of interrelationships between the examined characteristics.
3. Bearing in mind the obtained high values of determination coefficients (R^2) characterising the relationship between the volume of sapwood and heartwood and the proportion of these types of wood in tree crowns (dependent variable) and the breast height diameter, tree height and selected crown biometric (quantitative)features (independent variables), it seems reasonable to utilize these regularities as a method of timber quality assessment regarding the volume and proportion of sapwood and heartwood in the stems of the European larch developed in conditions of the fresh mixed broad-leaved forest.

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