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FLUCTUATIONS IN MEAN STEM VOLUME OF COMMON OAK (*QUERCUS ROBUR* L.) DEPENDING ON AGE OF TREES

Katarzyna Kaźmierczak[1], Witold Pazdrowski[2], Marek Szymański[2], Marcin Nawrot[2]

[1]Department of Forest Management, Poznań University of Life Sciences
Wojska Polskiego 71C, 60-625 Poznań, Poland
e-mail: kasiakdendro@wp.pl
[2]Department of Forest Utilization, Poznań University of Life Sciences
Wojska Polskiego 71A, 60-625 Poznań, Poland

Summary

In the study the level and variation of stem volume were determined in oaks aged from 10 to 140 years growing on two forest site types typical of oak, i.e. fresh mixed broadleaved forest and fresh broadleaved forest. Moreover, a dependence of stem volume of oaks on breast height diameter, height, breast height cross-section area and slenderness was investigated for the analyzed years of life of those trees. Volume was described by linear and multiple regression equations.

Key words and phrases: volume, common oak (*Quercus robur* L.), growth curve, age, linear regression, multiple regression

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1. Introduction

Volume of trees increases with age as a result of an increase in their dimensions, height and diameter at different heights. Volume of trees is a total of annual volume increments. The growth curve of volume may be presented as a function of age and successive growth phases may be distinguished in its course, similarly as in case of an increase in height, breast height diameter or breast height cross-section area. The growth curve of volume (as well as those of other characteristics) is shaped as a sloping and elongated letter S. Initially it grows very slowly – hyperbolically. After the phase of gradual growth there is a period of rapid change in volume, here the course is close to that of the linear function. This lasts up to very old age. Relatively rarely we may observe a convex, parabolic flexure of the curve. The duration of phases of both slow growth, a rapid increase in volume, as well as the late slow growth depends on the species, social class of tree position, tending interventions and site quality (Assmann 1968, Borowski 1974, Jaworski 2004).

Detailed analyses of growth and increment of trees as well as factors affecting their size and variation are primary fields of study in forestry. Insight into changes occurring in tree growth contributes to appropriate silvicultural measures in the forest economy and improved growth models of trees of different species. Growth models present relationships between characteristics of trees and entire stands mainly in the form of mathematical functions (Zasada 1999a). One of the stages in the development of models is to elaborate empirical formulas for the determination of volume. Formulas were developed for pine (Bruchwald 1973, 1978, Bruchwald, Dudek 1978, Bruchwald, Rymer-Dudzińska 1978a, b), spruce (Bruchwald, Rymer-Dudzińska 1981, 1987, Bruchwald, Wróblewski 1993), fir (Bruchwald 1992), oak (Bruchwald et al. 1994) and black alder (Dudzińska and Bruchwald 2003). Moreover, growth models were prepared for pine (Bruchwald 1986), spruce (Bruchwald et al. 1999), fir (Zasada 1995, 1999b), oak (Bruchwald et al. 1996) and black alder (Bruchwald et al. 2003).

2. The aim and scope of the study

In order to broaden and enhance knowledge on fluctuations of volume with age in oaks and to improve growth models, the aim of this study was especially:

1. to determine the size and variation in stem volume of oaks aged from 10 to 140 years, growing on two forest site types typical of oak, i.e. fresh mixed broadleaved forest and fresh broadleaved forest,

2. to investigate the correlation betwen stem volume in oaks and breast height diameter, height, breast height cross-section area and slenderness in analyzed years of life of those trees and

3. to describe volume with linear and multiple regression equations.

3. Experimental material and methodology

Experimental material comprised common oak (*Quercus robur* L.) growing in fresh mixed broadleaved forest and fresh broadleaved forest sites in the Łopuchówko Forest Division (the Regional Directorate of State Forests in Poznań). Investigations were conducted in stands, in which oak was found as the main species with the proportion of oak ranging from 80 to 100%. Admixture consisted of such tree species as common beech, hornbeam, silver birch, Norway maple, sycamore maple, black alder, aspen, common ash, mazzard, Scots pine, European larch and Norway spruce. In each stand a 1ha mean sample plot was established, in which in accordance with principles of the Urich diameter class method (Grochowski 1973) three mean sample trees were selected (a total of 33 trees). Trees were felled and measured. Complete stem analysis was performed on felled mean sample trees in 2m sections. Major measurement data characterizing analyzed trees at felling are given in Table 1.

Table 1. Selected measured characteristics of trees

Characteristic	N	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation (%)
age (years)	33	92	41	148	33.96	37.11
height (m)	33	24.8	18.3	34.3	5.04	20.29
Breast height diameter outside bark (cm)	33	31.48	14.55	56.85	11.17	35.49
volume (m^3)	33	1.11	0.18	3.81	0.93	83.43

Stem analysis was performed in years of life of those trees in 10-year periods. This facilitated a comparison of values of analyzed characteristics for a total of 285 stems of different age (from 10 to 140 years). Stem analysis is a method to investigate changes in different characteristics of trees during their lifetime. Thanks to this analysis we may in a way determine the life history of the analyzed tree. This method is based on the number and width of annual rings determined on cross stem sections collected from different heights along the stem. Discs were cut from stems in mid-length of adopted 2m sections (i.e. they were collected from a height of 1, 3, 5, 7 m, etc. starting from the base of the tree). Additionally, blocks were collected from the base of trees (height 0.0 m) and breast height, the characteristic diameter of a tree (height of 1.3 m). Tree age was determined based on the number of rings from the base of the tree. The disc from a height of 1.3 m made it possible to follow fluctuations in breast height diameter with age of the tree. Rings were counted on all discs, diameters were established and measured in years of life of those trees (in this experiment it pertained to the age of 10, 20, 30 ... up to 140 years). On this basis diameters were determined, which a given tree had at respective heights in individual period of life.

The conducted stem analysis in the years of life of trees made it possible to compare characteristics and to draw general conclusions concerning the development of analyzed oaks for a total of 285 stems of different age (from 10 to 140 years). One of the 33 oaks aged 10 years did not yet reach the height of 1.3 m. At that height one of the basic and characteristic features of a tree is measured - a diameter called breast height diameter. This measurement characteristic was used for further analyses, thus this tree for the youngest age group was not included in the calculations. In the presented study the focus was on an increase in tree volume.

4. Results

Mean volume of oaks increased with age of those trees from 0.0036 m^3 at the age of 10 years to 1.8707 m^3 at the age of 140 years (tab. 2, Figs. 1, 2). Coefficient of variation in this characteristic showed an opposite trend, since it decreased with age from almost 110% at the age of 10 years to less than 30% at the age of 140 years (tab. 2, Fig. 1). The median of volume, apart from the age of 110 years was lower that the arithmetic mean. The range of volume generally increased with age of trees from 0.0134 m^3 in the youngest trees to 1.9973 m^3 in 120-year old trees, to decrease and remain stable at approx. 1.18 m^3 in older trees (tab. 2). For all stems, irrespective of age, mean volume was 0.3891 m^3, with a variation of as much as over 134%.

Table 2. Selected statistical characteristics of volume for analyzed oak stems

Age	N	mean	Median	Minimum	Maximum	range	Standard deviation	Coefficient of variation
		m^3	m^3	m^3	m^3	m^3	m^3	(%)
10	32	0.0036	0.0017	0.0002	0.0136	0.0134	0.0040	109.76
20	33	0.0249	0.0152	0.0012	0.1134	0.1121	0.0241	96.78
30	33	0.0681	0.0528	0.0067	0.2443	0.2376	0.0547	80.31
40	33	0.1364	0.1200	0.0176	0.4151	0.3975	0.0935	68.60
50	28	0.1958	0.1790	0.0411	0.5214	0.4804	0.1127	57.52
60	25	0.3014	0.2852	0.0743	0.7336	0.6593	0.1695	56.25
70	22	0.4000	0.3693	0.1199	0.8392	0.7193	0.2033	50.82
80	20	0.5630	0.5073	0.1768	1.1607	0.9838	0.2682	47.64
90	16	0.7873	0.7569	0.2432	1.4516	1.2083	0.3401	43.20
100	15	0.9957	0.9687	0.3079	1.8462	1.5383	0.4231	42.49
110	10	1.2743	1.3041	0.3786	2.2860	1.9074	0.5843	45.85
120	8	1.6247	1.6040	0.8357	2.8330	1.9973	0.6649	40.92
130	6	1.5633	1.5249	0.9872	2.1711	1.1839	0.4711	30.13
140	4	1.8707	1.7713	1.3791	2.5611	1.1820	0.5540	29.62
total	285	0.3891	0.1722	0.0002	2.8330	2.8328	0.5232	134.46

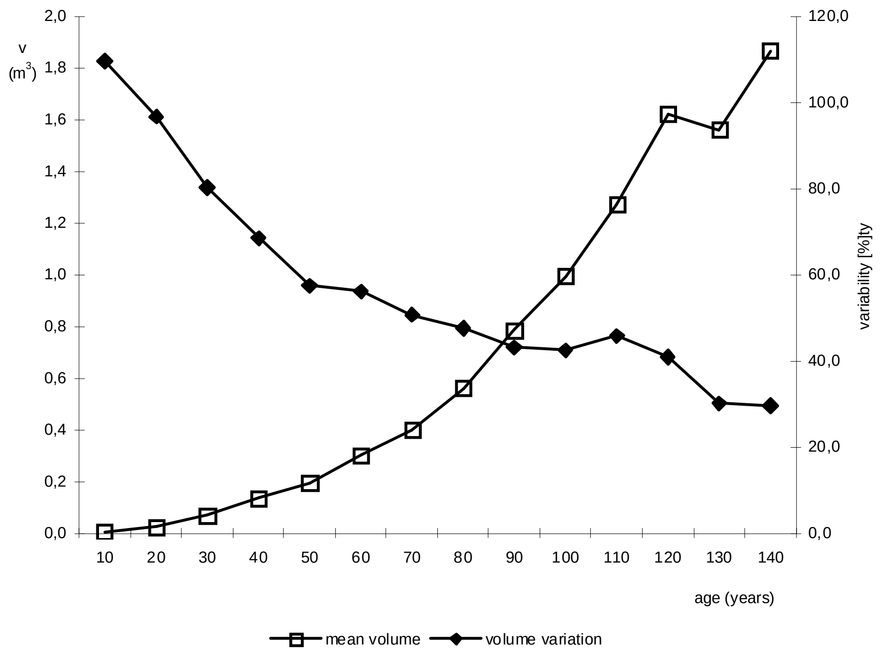

Fig. 1. Changes with age in mean volume of oak stems and its variation

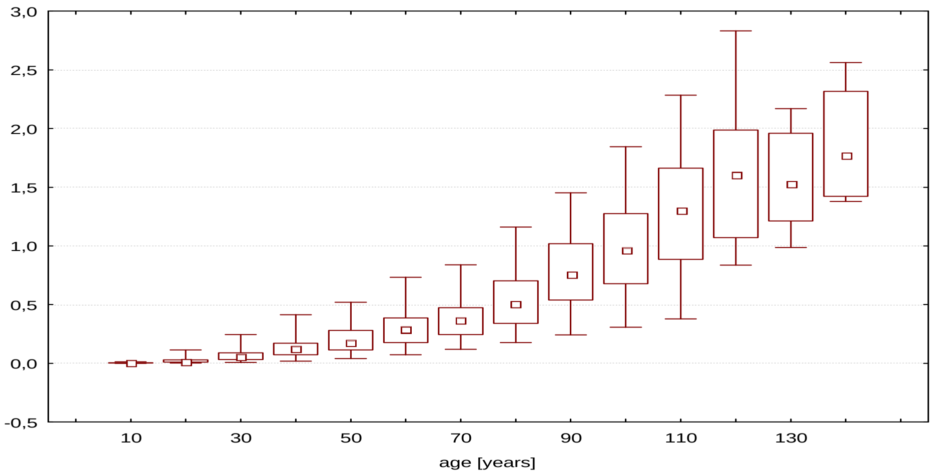

Fig. 2. A comparison of characteristics of stem volume for oaks in successive years in life of trees (boxes with tendrils present the range, the 1st and 3rd quartile and median)

Table 3. Coefficients of correlation between the volume of trees (V) and breast height diameter (d), height (h), breast height cross-section area (g) and slenderness (s) at analyzed age (w)

Age (w)	N	Breast height diameter (d)	Height (h)	Breast height cross-section area (g)	Slenderness
10	32	0.836*	0.679*	0.819*	-0.190
20	33	0.948*	0.739*	0.942*	-0.407*
30	33	0.951*	0.764*	0.960*	-0.446*
40	33	0.956*	0.759*	0.961*	-0.459*
50	28	0.944*	0.715*	0.940*	-0.533*
60	25	0.963*	0.706*	0.959*	-0.591*
70	22	0.957*	0.676*	0.942*	-0.465*
80	20	0.944*	0.687*	0.928*	-0.333
90	16	0.932*	0.699*	0.912*	-0.280
100	15	0.945*	0.683*	0.932*	-0.373
110	10	0.943*	0.819*	0.935*	-0.387
120	8	0.918*	0.718*	0.915*	-0.364
130	6	0.860*	0.798	0.872*	0.024
140	4	0.803	0.662	0.821	-0.197

*statistically significant at α = 0.05

The correlation stem volume in oaks and breast height diameter, height, breast height cross-section area and slenderness was investigated in analyzed years of life of trees (tab. 3). The volume of trees increases with an increase in breast height diameter, height and breast height diameter. A statistically significant correlation was found in case of most analyzed years of life of trees (tab. 3). In relation to slenderness a negative correlation was observed, although it was statistically significant (at $\alpha = 0.05$) only in trees aged from 20 to 70 years.

Moreover, the analysis included the relationship of volume with breast height diameter, height, age and slenderness for all trees analyzed jointly. Results of calculations are given in Table 4. Volume was described with linear and multiple regression equations, assuming the above mentioned characteristics of trees as independent variables. The regression equations were estimated by the least squares method.

Table 4. The dependence of volume of oaks on selected characteristics of trees (V – volume of trees, d – breast height diameter, h – height, s – slenderness, w – age)

Characteristics of trees Independent variables			Regression equation coefficients $V = a + bx_1 + cx_2 + fx_3$				R	$R_{partial}$			
x_1	x_2	x_3	a	b	c	f		d	h	w	s
d			-0.3880	0.0431			0.920				
h			-0.4868	0.0542			0.826				
w			-0.3245	0.0130			0.844				
s			1.3574	-0.9712			-0.488				
d	h	w	-0.3421	0.0475	-0.0121	0.0013*	0.922	0.662	-0.168	0.081*	
d	h		-0.3454	0.0496	-0.0099		0.922	0.726	-0.149		
d	h	s	-0.9462	0.0718	-0.0315	0.5500	0.938	0.764	-0.398		0.451

*statistically non-significant at $\alpha = 0.05$

Volume increased with an increase in breast height diameter, height and age and at the decreasing slenderness factor. Volume was related the most strongly with breast height diameter (0.920), while the relationship was slightly weaker for age (0.844) and height (0.826), being the weakest for slenderness (-0.488).

After excluding the effect of height the relationship of volume with breast height diameter was slightly weaker (0.726). In turn, after the exclusion of the effect of diameter measured at a height of 1.3 m the dependence of volume on height was considerably weaker, receiving also the negative sign (-0.149). These results may indicate a more intensive growth of breast height diameter with an increase in height. After the effect of breast height diameter and height were excluded, the correlation between volume and slenderness assumed the positive sign (0.451), which may indicate a higher intensity of the increase in breast height diameter.

5. Conclusions

1. Mean volume of oaks increased with age of trees and its coefficient of variation decreased with age from almost 110% at the age of 10 years to less than 30% at the age of 140 years (table 2).

2. Volume of trees increased with an increase in breast height diameter, height and breast height cross-section area at a decreasing slenderness (table 3).

3. The relationship of volume with breast height diameter was the strongest (0.920), slightly weaker with age (0.844) and height (0.826), while the weakest with slenderness (-0.488, table 4).

4. The relationship of volume with breast height diameter after the exclusion of the effect of height was slightly weaker (0.726, table 4).

5. The dependence of volume on height after the exclusion of the effect of breast height diameter assumed the negative sign and decreased considerably (-0.149, table 4).

6. The dependence of volume on age after the exclusion of the effect of breast height diameter and height was statistically non-significant (0.081, table 4).

7. Volume of oaks can be estimated by formula:

$$V = -0.9462 + 0.0718\ d - 0.0315\ h + 0.5500\ s.$$

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ZMIANY ŚREDNIEJ MIĄŻSZOŚCI PNIA DĘBU (*QUERCUS ROBUR* L.) W ZALEŻNOŚCI OD WIEKU DRZEWA

Streszczenie

W pracy ustalono wielkość i zmienność miąższości pni dębów w wieku od 10 do 140 lat wyrosłych na dwu typowych dla dębu siedliskowych typach lasu – lasu mieszanego świeżego i lasu świeżego. Zbadano także zależność miąższości pni dębów od pierśnicy, wysokości, powierzchni przekroju pierśnicowego i smukłości w rozpatrywanych latach życia drzew. Opisano ponadto miąższość liniowymi i wielorakimi równaniami regresji.

Słowa kluczowe: miąższość, dąb szypułkowy (*Quercus robur* L.), krzywa wzrostu, wiek, regresja liniowa, regresja wieloraka

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