Colloquium Biometricum 38
2008, 107–116

ANALYSIS OF GROWTH AND INCREMENT IN HEIGHT OF COMMON OAK (QUERCUS ROBUR L.)

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

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

Summary

The paper presents the volume and variation of height and periodic increment in height of common oaks aged 10 to 140 years, growing in two forest site types typical of this species – fresh mixed broadleaved forest and fresh broadleaved forest. Experimental material included selected results of stem analysis of 33 oaks (aged 41 to 148 years) coming from 11 stands. Stem analysis was performed at 10-year intervals during the life of trees, which made it possible to compare values of analyzed traits of trees for a total of 285 stems of different ages.

Key words and phrases: common oak, height, increment in height, growth curve, increment curve, coefficient of variation, correlation coefficient, linear regression, multiple regression

Classification AMS 2000: 62F25, 62J05

1. Introduction

Growth and increment of a tree as well as factors affecting its size and variation belong to the basic fields of research in forestry (Assmann 1968, Borowski 1974). Insight into changes occurring in the growth of trees contributes to an appropriate course of silvicultural procedures conducted in the forest management unit (Jaworski 2004). Research in this field has been conducted primarily in relation to Scots pine. This situation is perfectly understandable as it is the main forest-forming species in Poland. The fluctuations in growth and volume increment or selected volume elements have been analyzed. Growth dynamics in pine have been investigated by e.g. Szymański (1963), Żółciak (1963), Ważyński (1967), Borowski, Grochowski (1969) and Lemke (1971, 1972a, 1972b, 1984, 1988).

Height and its periodic increment belong to major dendrometric characteristics. They have a direct effect on accuracy in case of estimation of volume and volume increment of a single tree and the entire stand (Grochowski, 1960; Gieruszyński, 1961; Bruchwald, 1971, 1999). Periodic increment in height is a variable characteristic. It depends on the age of trees and growth conditions (Beker, 1997; Lemke, 1972a, 1972b; Najgrakowski, 1998; Rymer-Dudzińska, 1997, 1998; Kaźmierczak, 2005).

2. The objective and scope of studies

The aim of the study was to analyze fluctuations with age in the volume and variation of height in oaks growing in two forest site types – fresh mixed broadleaved forest (LMśw) and fresh broadleaved forest (Lśw). Similar analyses were conducted for the current 10-year increment in height. Moreover, the study included the strength of relationships between height and increment in height with selected traits of trees. Based on determined dependencies equations of linear and multiple regression were developed in order to estimate height and its periodic increment in oaks.

3. Experimental material and methodology

Experimental material included selected results of stem analyses of 33 oaks (aged from 41 to 148 years) coming from 11 stands (the Łopuchówko Forest Division, the Poznań Regional Directorate of State Forests). In each of the 11 stands a 1 ha experimental plot was established, in which – following principles of variant I of the Urich method - 3 mean sample trees were selected (a total of 33 stems). Some stands (6 out of 11) were growing in fresh mixed broadleaved forest sites (LMśw), while others (the other 5) – in fresh broadleaved forest sites (Lśw). Major measurement data characterizing investigated trees at felling are presented in Table 1.

Table 1. Characteristics of selected measurement traits of trees at felling

Trait	N	$\bar{x}$	min	max	S_{dx}	V (%)
w (age – years)	33	92	41	148	33.96	37.11
h (height – m)	33	24.8	18.3	34.3	5.04	20.29
d_{zk} (breast height diameter outside bark – cm)	33	31.48	14.55	56.85	11.17	35.49
k (double bark thickness at a height of 1.3 m – cm)	33	1.87	0.90	3.40	0.63	33.59
v (volume established in sections – m^3)	33	1.11	0.18	3.81	0.93	83.43

Complete stem analyses were conducted on felled mean sample trees in 2 m sections. Stem analyses were conducted during the life of trees at 10-year intervals. This facilitated a comparison of values of analyzed traits of trees for a total of 285 stems of different ages (from 10 to 140 years). Stem analysis is a method to investigate changes in different characteristics of a tree during its lifetime. Thanks to this type of analysis we may determine the lifetime history of this tree. This method is based on the number and width of annual rings identified in cross-sections collected from different stem heights. Discs were cut from stems at half-length of assumed 2-m section (i.e. they were collected from a height of 1, 3, 5, 7 m, etc. counting from the base of the tree). Additionally, blocks were collected from the base of trees (height of 0.0 m) and from breast height – the characteristic diameter of a tree (a height of 1.3 m). The age of trees was determined based on the number of annual rings from the base. The disc collected from a height of 1.3 m made it possible to follow the fluctuations of breast height diameter with age. On all discs rings were counted, diameters were identified and measured in years of life of the tree (in this experiment this pertained to the age of 10, 20, 30 ... up to 140 years). On this basis diameters were obtained, which a tree had at respective heights in individual periods of life.

Results of complete stem analysis made it possible to plot growth curves and increment curves for individual traits of trees, as well as determine the stem profile, which in a simple way illustrates ratios of increment in height and volume increment as well as the development of stem form with age. The picture of tree development in terms of height, diameter, volume and other characteristics of trees was obtained based on stem analysis. Conducted stem analysis during the lifetime of a tree made it possible to compare traits and draw general conclusions concerning the development of investigated oaks for the total number of 285 stems of different ages (from 10 to 140 years). One of the 33 oaks aged 10 years did not reach the height of 1.3 m. At that height one of the basic and characteristic traits of trees is measured, i.e. a diameter referred to as the diameter at breast height. This measurement trait was used in further analyses, thus this tree for the youngest age class was excluded from the calculations. The presented study focused on growth and increment for only one trait, i.e. tree height.

4. Results

Analysis of height growth and its increment was started at the age of 10 years. Fluctuations of mean height of oaks with age are presented in Fig. 1 (on the left). Mean height of a tree grew with age from 3.95 m to 30.73 m (tab. 2). Height growth pertains both to the arithmetic mean, established on the basis of measurements of many trees as well as single trees. Height of individual trees fell within a wide range in the course of 140 years (from 2.01 m to 33.35 m).

Table 2. Selected statistical characteristics of height and current 10-year increment in height of analyzed oak stems

Age	N	Height *h*					Increment in height *Zh*				
		$\bar{x}$	min	max	s_{dx}	V	$\bar{x}$	min	max	s_{dx}	V
	szt.	m	m	m	m	(%)	m	m	m	m	(%)
10	32	3.95	2.01	8.00	1.26	31.93	3.95	2.01	8.00	1.26	31.93
20	33	7.86	3.75	12.00	2.07	26.38	4.00	1.67	6.80	1.34	33.46
30	33	11.61	7.15	17.00	2.72	23.48	3.74	1.82	5.34	1.06	28.43
40	33	14.72	8.69	20.67	3.20	21.74	3.11	1.17	4.60	0.91	29.11
50	28	16.35	10.07	20.85	2.85	17.44	2.45	1.21	4.86	0.81	33.06
60	25	18.28	11.50	22.75	3.16	17.31	2.29	1.00	3.68	0.79	34.50
70	22	19.96	13.20	25.50	3.41	17.07	2.14	1.02	3.88	0.79	36.79
80	20	21.93	15.20	27.67	3.81	17.37	2.02	0.66	3.82	0.89	44.22
90	16	24.35	17.13	29.80	4.21	17.29	2.04	1.11	3.40	0.63	30.59
100	15	26.09	18.29	31.38	4.27	16.35	1.45	1.01	1.89	0.32	21.83
110	10	26.55	19.63	31.94	4.63	17.43	1.34	0.56	3.29	0.78	58.12
120	8	28.06	20.88	32.09	4.30	15.31	1.33	0.65	2.58	0.63	47.43
130	6	28.30	22.82	31.94	4.05	14.33	1.36	0.72	2.78	0.76	56.30
140	4	30.73	25.44	33.35	3.61	11.75	1.77	0.72	2.62	0.83	47.09
all	285	16.18	2.01	33.35	7.98	49.32	2.78	0.56	8.00	1.32	47.62

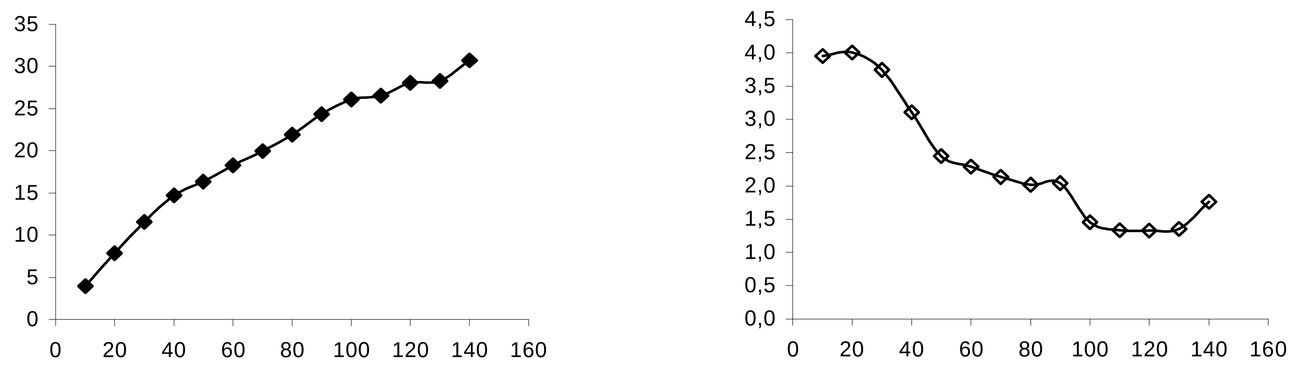

Fig. 1. Changes with age of mean height (growth curve on the left) and current 10-year increment in height (increment curve on the right) of oaks

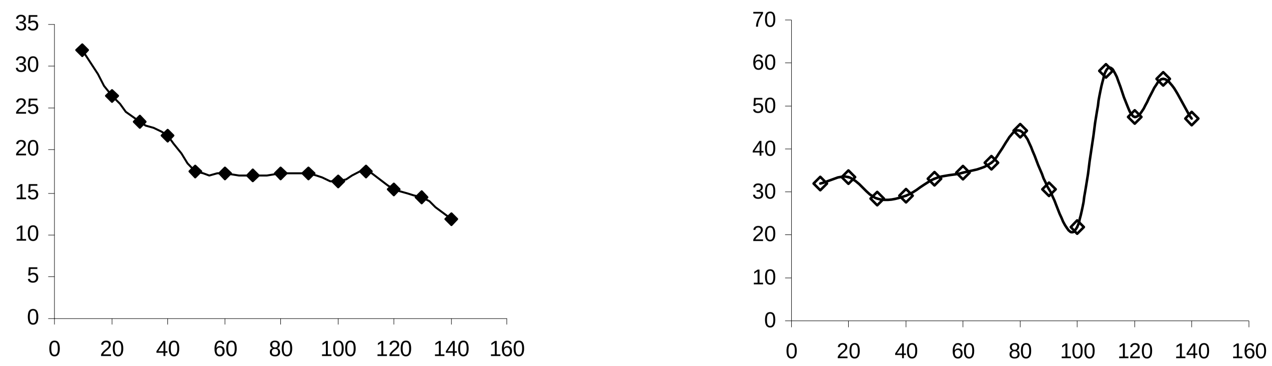

Fig. 2. Changes with age in variation of height (on the left) and current 10-year increment in height (on the right) of oak stems

The highest variation in height, expressed in the coefficient of variation, in analyzed oaks was found in the youngest, 10-year trees (31.93%). With age the variation in height generally decreased (tab. 2, Fig. 2). Between the age of 50 to 110 years the variation was found to stabilize at approx. 17%, followed by a repeated drop to 11.75% at the age of 140 years. The range of height grew up to the age of 50 years, next it decreased slightly and remained at a similar level up to the age of 100 years, followed by a decrease.

The curve of current periodic increment in height is different in shape from the growth curve for this trait (Fig. 1). The peak of current increment in height in oaks was found in the increment period of 10-20 years, reaching 4.00 m at the end of this period (tab. 2). After this culmination increment in height decreased. An opposite trend was recorded for the variation in this trait, which generally grew with age, with a considerable slump in the period from 80 to 100 years in the lives of trees (tab. 2, Fig. 2). Increment in height exhibited a much bigger variation than tree height. Differences between maximum and minimum increments in height (the range) decreased with age.

Their strength was determined for relationships of height (*h*) and periodic increment in height (*Zh*) with selected traits of trees. For the purpose of analyses the simplest traits were selected, easily determined in standing trees with no need to fell them. Correlation coefficients were calculated for the correlation of height with its periodic increment and age (*w*), breast height diameter inside bark (*d*), periodic increment in breast height diameter (*Zd*). Similar calculations were used in relation to increment in height. The strongest correlation with height was found for breast height diameter inside bark (0.922) and tree age (0.903). A weaker relationship with height was recorded for its periodic increment (-0.501), while the weakest with periodic increment in breast height diameter (-0.214). All obtained correlation coefficients were statistically significant at $\alpha = 0.05$. The correlation was negative with the two latter traits. This means that with an increase in height the increment in height and increment in breast height diameter decreased. In case of increment in height the calculated correlation coefficients with the same traits were slightly smaller, but also statistically significant. An exception in this respect was the relationship of increment in height with increment in breast height diameter (0.454), which was bigger than that found for height and increment in breast height diameter (-0.214). For age and periodic increment in height the correlation coefficient was -0.666, while for breast height diameter and increment in height it was -0.516.

Results concerning the dependence of height and increment in height on age, breast height diameter and increment in breast height diameter were promising and thus equations of linear and multiple regressions were developed in order to determine the height of oaks and increments in height.

As a result of estimation of parameters for regression equations the following equations were obtained in order to determine height of oaks:

$$h = 4.533259 + 0.211777 \cdot w \quad (3.1)$$
$$h = 4.291777 + 0.658594 \cdot d \quad (3.2)$$
$$h = 3.888593 + 0.085036 \cdot w + 0.421857 \cdot d \quad (3.3)$$

In order to determine periodic increment in height of oaks regression equations were developed, which took the form:

$$Zh = 4.200766 - 0.025886 \cdot w \quad (3.4)$$
$$Zh = 2.699722 - 0.037956 \cdot w + 0.081604 \cdot h - 0.007125 \cdot d + 0.299348 \cdot Zd \quad (3.5)$$
$$Zh = 2.762335 - 0.039260 \cdot w + 0.076986 \cdot h + 0.285569 \cdot Zd \quad (3.6)$$
$$Zh = 1.841383 + 0.053585 \cdot h - 0.092782 \cdot d + 0.536377 \cdot Zd \quad (3.7)$$

The fit of all equations was assessed. Results are given in Table 3.

Table 3. Coefficients of linear, multiple and partial correlation of height and increment in height with selected traits of trees used in regression equations

Equation	Traits of trees – independent variables				Correlation coefficients		R^2	$R_{partial}$			
	x_1	x_2	x_3	x_4	linear	multiple		*w*	*h*	*d*	*Zd*
(3.1)	*w*				0.903		0.815				
(3.2)	*d*				0.922		0.851				
(3.3)	*w*	*d*				0.934	0.872	0.380		0.556	
(3.4)	*w*				-0.666		0.443				
(3.5)	*w*	*h*	*d*	*Zd*		0.745	0.554	-0.423	0.277	-0.025*	0.295
(3.6)	*w*	*h*	*Zd*			0.744	0.554	-0.533	0.284		0.337
(3.7)	*h*	*d*	*Zd*			0.677	0.458		0.153	-0.358	0.507

*correlation coefficient non-significant at $\alpha = 0.05$

Empirical development of regression functions at a similar level of accuracy describes variation of height in oaks. Values of age may be used to describe 81.5% variation in height, while slightly more, i.e. 85.1% for breast height diameter, whereas for both traits jointly it was 87.2% (tab. 3). After the exclusion of the effect of age the strength of the dependence between height and breast height diameter was smaller (0.556). When the effect of breast height diameter was excluded, the strength of the relationship of height with age was much smaller, as it amounted to only 0.380 (tab. 3).

Regression equations for the calculation of increment in height of oaks at a much lower level explain variation in increment in height (tab. 3). Age of oaks explain only 44.3% variation in 10-year current increment in height. When we considered four traits, i.e. age, height, breast height diameter and its periodic increment to be independent variables, the variation of increment in height was explained in 55.4%. In this equation (3.5) the coefficient at *d* was statistically non-significant, which was confirmed by the coefficient of partial correlation at the excluded effect of the other traits. After the elimination of this measurement characteristic from the equation the input of labour was reduced at the collection of data for calculations, which did not result in a reduced fit of the developed function (3.6) of multiple regression. Variation in height, breast height diameter and its periodic increment (equation (3.7)) was explained in 45.8%.

In relation to the developed functions for the determination of increment in height it is of interest to point to the character of dependence between tree height and increment in height at the exclusion of the effect of other traits. This correlation was weaker, but it changed into a positive one (tab. 3). This may have been caused by a higher intensity of growth in breast height diameter of trees in comparison to their height growth.

5. Conclusions

1. Mean tree height increased with age.
2. This variation in height generally decreased with age. The biggest variation in height of analyzed oaks was found in the youngest trees, amounting to 31.93%. In the oldest trees it dropped to 11.75%.
3. The peak of the current 10-year increment in height of oaks was recorded at the age of 20 years and it amounted to 4.00 m, with the increment in height decreasing afterwards.
4. Increment in height exhibited a much bigger variation than tree height and generally increased with age, although this increase was irregular.
5. Breast height diameter inside bark and tree age had the strongest correlations with height, while the correlation was weaker for periodic increment in height and increment in breast height diameter.
6. In case of increment in height calculated correlation coefficients with the same traits were slightly smaller.
7. In order to determine height of oaks and periodic increment in height new empirical functions were proposed, which practical applications should be assessed in the future, based on independent empirical material.

References

Assmann E. (1968). *Nauka o produkcyjności lasu*. PWRiL, Warszawa.

Beker C. (1997). *Dendrometryczna charakterystyka wybranych drzewostanów sosnowych znajdujących się pod wpływem imisji przemysłowych.* Wyd. SGGW, Warszawa.

Borowski M. (1974). *Przyrost drzew i drzewostanów.* PWRiL, Warszawa.

Borowski M., Grochowski J. (1969). Wyniki analizy pni drzewostanu sosnowego Lasów Rogowa. *Folia Forestalia Polonica*, series A, book 15, 9-55.

Bruchwald A. (1971). Metoda określania bieżącego przyrostu miąższości drzewostanu przy zastosowaniu właściwej liczby kształtu $f_{L/3}$. *Folia Forestalia Polonica*, series A, book 18, 99-131.

Bruchwald A. (1999). *Dendrometria.* Wyd. SGGW – AR, Warszawa.

Gieruszyński T. (1961). Badanie dokładności i doskonalenie sposobów oznaczania przyrostu miąższości drzewostanu za pomocą tabel miąższości. *Acta Agr. Silv.* Seria leśna I, 21-37.

Grochowski J. (1960). Metoda określania wstecz bieżącego przyrostu miąższości drzewostanu za pomocą tablic miąższości. *Folia Forestalia Polonica*, series A, book 4, 5-29.

Jaworski A., (2004). *Podstawy przyrostowe i ekologiczne odnawiania oraz pielęgnacji drzewostanów.* PWRiL. Warszawa.

Kaźmierczak K. (2005). Przyrost na wysokość i dokładność różnych sposobów jego określania na przykładzie wybranych drzewostanów sosnowych. *Roczniki AR w Poznaniu*, Rozprawy Naukowe, book 362.

Lemke J. (1968). Związek pomiędzy wielkością korony a przyrostem drzew w drzewostanach sosnowych. *PTPN*, vol. XXV, 43-90.

Lemke J. (1972a). Retrospektywna analiza wzrostu i przyrostu drzew w 50-letnim drzewostanie sosnowym. *Folia Forestalia Polonica*, series A, vol. 19, 5-23.

Lemke J. (1972b). Wyniki analizy strzał 35-letniego drzewostanu sosnowego. *PTPN*, t. XXXIV, 89-105.

Lemke J. (1984). Retrospektywna ocena intensywności przyrostu miąższości drzew w drzewostanach sosnowych II i III klas wieku. *PTPN*, vol. LVIII, 53-63.

Lemke J. (1988). Retrospektywna analiza właściwej liczby kształtu strzały $f_{0,1h}$ w młodszych drzewostanach sosnowych *PTPN*, vol. LXVI, 35-38.

Najgrakowski T. (1998). *Dendrometryczna charakterystyka wybranych drzewostanów sosnowych na terenach objętych w latach 1978-1983 gradacją brudnicy mniszki*. Manuscript. Katedra Dendrometrii AR w Poznaniu.

Rymer-Dudzińska T. (1997). Badania nad pięcioletnim przyrostem wysokości w drzewostanach sosnowych. *Sylwan* 10, 21-34.

Rymer-Dudzińska T. (1998). Statystyczna charakterystyka dziesięcioletniego przyrostu wysokości drzew w drzewostanach sosnowych. *Sylwan* 7, 67-79.

Szymański S. (1963). Dynamika rozwoju niekierowanych młodników sosnowych. *PTPN*, t. XV, book 3.

Ważyński B. (1967). Struktura i dynamika rozwoju drzewostanów sosnowych I i II klasy wieku *PTPN*, vol. XXI, book 2.

Żółciak E. (1963). Analiza kształtowania się przyrostów drzew w różnych okresach życia drzewostanów sosnowych na borze świeżym na przykładzie Nadleśnictwa Doświadczalnego WSR Zielonka. *Roczniki WSR w Poznaniu*, vol. XIV, 249-293.

ANALIZA WZROSTU I PRZYROSTU WYSOKOŚCI DĘBU SZYPUŁKOWEGO (*QUERCUS ROBUR* L.)

Streszczenie

W pracy przedstawiono wielkość i zmienność wysokości oraz okresowego przyrostu wysokości dębu szypułkowego dla drzew w wieku od 10 do 140 lat wyrosłych na dwu typowych dla tego gatunku siedliskowych typach lasu – lasu mieszanego świeżego i lasu świeżego. Materiał badawczy obejmuje wybrane wyniki analizy pniowej 33 dębów (w wieku od 41 do 148 lat) pochodzących z 11 drzewostanów. Analizę pniową wykonano w latach życia drzewa w okresach 10-letnich, co umożliwia porównanie wielkości analizowanych cech drzew dla łącznej liczby 285 pni w różnym wieku.

Słowa kluczowe: dąb szypułkowy, wysokość, przyrost wysokości, krzywa wzrostu, krzywa przyrostu, współczynnik zmienności, współczynnik korelacji, regresja liniowa i wielokrotna

Klasyfikacja AMS 2000: 62F25, 62J05