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CORRELATIONS AMONG CHOSEN TRAITS OF STANDING TREES IN 35-YEARS OLD PINE STANDS

Katarzyna Kaźmierczak, Tomasz Najgrakowski

Department of Forest Management
University of Life Sciences in Poznań
Wojska Polskiego 71c, 60 – 625 Poznań
e-mails: kkdendro@up.poznan.pl, dentomn@up.poznan.pl

Summary

The paper presents results of studies on dependency between chosen stem measurements – DBH (diameter at breast height), height, increment in breast height diameter, slenderness, current increment of tree volume and as tree crown dimensions – diameter, length and relative length of the crown, degree of crown spread. Material for analysis comprises results of measurements of 50 pines sampled in 35-year old stand. In view of the statistically significant dependence between volume increment of pine and measured tree traits the analysis of regression was conducted, assuming the investigated traits as explanatory variables. Regression equations were developed for the estimation of current tree volume increment. The backward stepwise regression was applied.

Keywords and phrases: crown diameter, crown length, diameter at breast height, height, degree of crown spread, crown length, relative length of the crown, stepwise regression, Scots pine (*Pinus sylvestris* L.)

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1. Introduction

The improvement of methods of calculating tree and stand volume increment is fundamental for forest mensuration and forest yield prediction. Insight into changes occurring in growth of trees contributes to an appropriate course of silvicultural procedures conducted in the forest management unit (Assmann 1968, Borowski 1974, Jaworski 2004). Growth dynamics of pines (the main forest-forming species in Poland) have been investigated by many researchers, e.g. Szymański (1963), Żółciak (1963), Ważyński (1967), Borowski, Grochowski (1969) and Lemke (1972a, 1972b, 1984, 1988). Tree volume increment is one of the most difficult parameters to measure and was established on felled trees. Regression function for tree volume increment have been developed as a function of easily measurable tree variables on standing tree. The volume increment models should be based on the variables that are normally measured in forest inventories or which can be easily estimated.

The aim of this study was:

- To determine the strength of the relationship between current volume increment stem measurements and crown dimensions,
- To develop regression equations for the estimation of tree volume increment basis of tree traits.

2. Empirical material and methods

Empirical material was collected in 35−years−old pure Scots pine stand growing on fresh conifer forest site in the Zielonka Experimental Forest District. The research material consisted of measurements of 50 pine trees. Sample trees were selected randomly from stand. The following was measured for each tree:

1) DBH in bark $d_{1.3}$ in two directions N−S and W−E with a tolerance of up to 0.1 cm; the arithmetic mean of those measurements was assumed as tree DBH.
2) Tree height h with a tolerance of up to 0.1 m.
3) Tree crown height with a tolerance of up to 0.1 m.
4) Crown projection area on the basis of the characteristic tree crown points (4 to 14) projected with the use of a crown projector;
5) Zd_5 5-year increment in breast height diameter with a tolerance of up to 0.01 cm.

Crown widths d_k expressed in meters were obtained from the crown projection area assumed as the area of a circle. Crown length l_k was calculated as the difference between total tree height and crown position height, while relative crown length l_k/h was the ratio of crown length and tree height. Slenderness was calculated as the ratio of height in m to breast height diameter in cm $h/d_{1.3}$. The degree of crown spread d_k/h was calculated as a ratio of crown diameter to tree height. Tree slenderness was calculated as a ratio of tree height to diameter at breast height $h/d_{1.3}$. Slenderness is an important characteristic of a tree indicating its stability. Colinearity does not occur between diameter at breast height and tree height. Current volume increment in m^3 for the last 5 years (Zv_5) was determined by section analysis for each felled tree. Regression analysis was performed using the backward elimination method at the level of significance of 0.05 (the StatSoft, Inc. 2011. STATISTICA data analysis software system, version 10).

3. Results

Basic descriptive statistics of traits are presented in Table 1. Current stem volume increment Zv_5 appeared to be the most variable from among traits under research, with variation coefficient of 81.51%. It was followed by another incremental trait - current increment of diameter at breast height Zd_5 (55.78%). The crown dimensions were found to be less variable, with coefficients of variation ranging from 19.04% for relative crown length l_k/h to 31.50% for crown diameter. Among stem dimensions height h appeared to be the less variable trait (10.09%) followed by slenderness $h/d_{1.3}$ (19.24%) and diameter at breast height $d_{1.3}$ (27.11%).

Analysis of Pearson correlation coefficients among traits shown all the traits are significantly correlated one with another. As shown in Table 2, the strongest correlation – with Pearson coefficient absolute values exceeding 0.9 – was observed between Zv_5 and $d_{1.3}$ – 0.935, Zv_5 and Zd_5 – 0.912, $d_{1.3}$ and $h/d_{1.3}$ – -0.937, dk and d_k/h – 0.948, l_k and l_k/h – 0.951. Majority of Pearsons coefficients were of positive sign; the only trait negatively correlated with all the others was slenderness $h/d_{1.3.}$

Table 1. Characteristic of selected measurable traits of trees

Tree traits	$\bar{x}$	min	max	s_{dx}	V (%)
Zv_5 (m^3)	0.0165	0.0015	0.0671	0.0134	81.51
$d_{1.3}$ (cm)	12.34	7.30	21.90	3.35	27.11
h (m)	13.31	10.42	16.25	1.34	10.09
Zd_5 (cm)	0.75	0.10	1.50	0.42	55.78
d_k (m)	1.96	0.62	3.30	0.62	31.50
d_k/h	0.15	0.05	0.24	0.04	27.18
l_k (m)	4.92	2.80	9.01	1.31	26.59
l_k/h	0.37	0.23	0.55	0.07	19.04
$h/d_{1.3}$	1.13	0.74	1.65	0.22	19.24

Current stem volume increment Zv_5 shown the strongest correlation with diameter at breast hight $d_{1.3}$ (0.935) and its current increment – Zd_5 (0.912), then with crown length l_k (0.846), tree height h (0.842), slenderness $h/d_{1.3}$ (-0.797), crown diameter d_k (0.771) and relative crown length l_k/h (0.702); the weakest, however still significant correlation was recorded with degree of crown spread d_k/h (0.567).

Table 2. The Pearson correlation diagram

Tree traits	Zv_5	$d_{1.3}$	h	Zd_5	d_k	d_k/h	l_k	l_k/h
$d_{1.3}$	0.935*							
h	0.842*	0.845*						
Zd_5	0.912*	0.859*	0.829*					
d_k	0.771*	0.780*	0.652*	0.772*				
d_k/h	0.567*	0.594*	0.387*	0.591*	0.948*			
l_k	0.846*	0.800*	0.802*	0.764*	0.673*	0.483*		
l_k/h	0.702*	0.655*	0.589*	0.623*	0.593*	0.476*	0.951*	
$h/d_{1.3}$	-0.797*	-0.937*	-0.685*	-0.766*	-0.756*	-0.640*	-0.676*	-0.581*

*The correlation coefficient significant at the level α = 0.05

On the basis of the above presented correlations, three multiple regression equations were proposed for current stem volume increment (Zv5) approximation:

$$Zv_5 = -0.008 + 0.005 \cdot d_{1.3} + \\ -0.006 \cdot h + 0.002 \cdot l_k + 0.043 \cdot d_k - 0.508 \cdot \frac{d_k}{h} + 0.029 \cdot \frac{h}{d_{1.3}} \tag{3.1}$$

$$Zv_5 = -0.015 + 0.005 \cdot d_{1.3} + \\ -0.006 \cdot h + 0.044 \cdot d_k - 0.522 \cdot \frac{d_k}{h} + 0.032 \cdot \frac{h}{d_{1.3}} \tag{3.2}$$

$$Zv_5 = 0.030 + 0.004 \cdot d_{1.3} + \\ -0.008 \cdot h + 0.019 \cdot l_k + 0.013 \cdot Zd_5 - 0.243 \cdot \frac{l_k}{h} + 0.025 \cdot \frac{h}{d_{1.3}} \tag{3.3}$$

The current DBH increment (Zd_5), despite showing the second strongest correlation with Zv_5, was omitted in equations 3.1 and 3.2. Measurement of Zd_5 at standing trees is work consuming and demands invasive methods of sample extraction, which can weaken the tree.

The degree of crown spread d_k/h – although showing the weakest correlation with Zv_5 – was considered as independent variable in equations 3.1 and 3.2, being quite important and the indicator of tree growth space – and one of the only two of that category present in the research.

Table 3. Multiple and partial correlation coefficients for the tree volume increment dependence on the selected characteristics of trees

Equation	R multiple	R partial							
		$d_{1.3}$	h	Zd_5	d_k	d_k/h	l_k	l_k/h	$h/d_{1.3}$
(3.1)	0.978	0.704*	-0.578*		0.557*	-0.535*	0.377*		0.509*
(3.2)	0.976	0.718*	-0.528*		0.542*	-0.515*			0.522*
(3.3)	0.990	0.738*	-0.722*	0.810*			0.633*	-0.604*	0.556*

*The correlation coefficient significant at the level $\alpha = 0.05$

As shown in Table 3, coefficients of multiple correlation between Zv_5 and independent variables applied in equations 3.1, 3.2 and 3.3 assume values of 0.978, 0.976 and 0.990 respectively. Partial correlation coefficients between Zv_5 and explanatory variables are all statistically significant at the level $\alpha = 0.05$; the strongest correlations seems to exist in equation 3.3, with Zd_5 (0.810), $d_{1.3}$ (0.738), and h (-0.722); then in equation 3.2 with $d_{1.3}$ (0.718), d_k (0.542) and h (-0.528); finally in equation 3.1 with $d_{1.3}$ (0.704), h (-0.578) and d_k (-0.557). Other coefficients show slightly lower values; the lowest recorded partial correlation coefficient value occur for equation 3.1 between Zv_5 and l_k (0.377).

Therefore, it can be assumed that equation 3.3 will provide the best approximation of Zv_5; nevertheless, in case measuring the Zd_5 is undesired the other equations should be applied.

4. Discussions

As shown in literature, the volume increment per square meter of crown projection area diminishes with the growth of crown projection area in each biosocial class (Borowski 1968). With small crown projection area it diminishes quickly, and with great projection area the lapse happens slower. With the same crown projection area, the bigger the volume increment, the higher tree's position in vertical stand's structure is. The size of tree's volume increment under given conditions is determined by the size of assimilation apparatus and biosocial position.

Dudek (1969) showed that younger trees with similar crown projection area have bigger DBH increment and bigger basal area increment per DBH cross-sectional area unit (higher factor of volume increment intensity) than older trees.

Zajączkowski (1973) revealed the increase of volume increment with a increasing of crown projection area in biosocial classes. Trees of higher Kraft's classes were characterized with a higher volume increment than trees from lower classes with crowns of similar sizes.

Skrzyszewski (1995) in 11 spruce stands among the examined 15, showed the relation of crown length with current 10-year old increment in breast height cross section. Relative length of the crown influenced in an essential statistical way on this kind of tree increment was seen in 9 stands out of 15.

Svensson's (1998) research showed the necessity of taking into consideration relative crown length when defying basal area increment.

Jaworski and others (1988, 1995) showed that correlation factor between the relative crown length and increment of annual ring in younger stands was 0,579, and in older was 0,515.

The research by Kaźmierczak and others (2008) showed the influence of slenderness on DBH increment and volume increment. It was stated that with the increase in breast height cross section increment, the slenderness of trees diminished.

5. Conclusions

With the growth of diameter at breast height, height, 5-year increment in breast height diameter, crown diameter, degree of crown spread, crown length, relative crown length pine volume increment increases.

The strongest association of the tree volume increment was found with the diameter at breast height, increment in breast height diameter, height and crown length.

Volume increment of pine can be determined by regression equation in dependence to the diameter at breast height, height and crown length, current increment in breast height diameter, relative crown length and slenderness.

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